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I am submitting herewith a dissertation written by Kathryn A. King entitled “Climatic Adaptation and Postcranial Metric Variation in Precontact North America.” I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Anthropology.

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CLIMATIC ADAPTATION AND POSTCRANIAL METRIC VARIATION IN PRECONTACT NORTH AMERICA.

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Abstract

The purpose of this dissertation is to investigate patterns of variation in the postcranial skeleton of prehistoric American populations as they are related to variation in climate. Two ecogeographical rules proposed by Karl Bergmann (1847) and Joel Allen (1877) describe expected patterns of variation with widespread, warm-blooded species. Modern humans in the Old World largely conform to this pattern (Holliday 1997a). This study seeks to explore if the same patterns are present in the New World.

Skeletal material from 25 North American bioarchaeological collections was used in this analysis. A series of 29 measurements of the postcranial skeleton were collected from 854 individuals. These measurements were analyzed with respect to site-specific temperature and precipitation data using univariate and multiple regression analysis, analysis of size and shape using "Mosimann" type shape variables (Darroch and Mosimann 1985), and canonical correlation analysis.

The results of this study show that there is a significant relationship between climate and postcranial variation in this sample, particularly in measurements of long bone length and epiphyseal size. Radius and tibia length appear to be the most highly correlated with climate variables, as would be expected if thermoregulation is a significant biological stress (Holliday 1999).

Comparison between this sample and data collected from Old World samples suggest that adaptation to climate has occurred in North America, but not to the same degree as is seen in the Old World. This suggests that the relatively recent peopling of the Americas, as well as other factors such possible long-distance migrations, have influenced the potential effects of adaptation to climate.

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Chapter 1: Introduction

This study seeks to explore the potential role of climatic adaptation in the development of patterns of postcranial morphology in the pre-contact population of North America. Modern American Indians and First Nations are the descendents of immigrants who likely derived from a single group or several geographically proximate groups in Asia. They were subject to similar climate-related selective pressures during the migration process, regardless if their ancestors' route was coastal or terrestrial. From this founding group or groups, a multitude of groups emerged and settled every habitat in the Americas, from deserts to rainforests to the polar regions. This population expansion resulted in cultural and biological diversification. It is the biological component of this diversification that this work seeks to explore, particularly those features associated with climatic adaptation in the postcranial skeleton.

The hypothesis of this work is that indigenous groups have inhabited the New World for a sufficient amount of time to have adapted to the specific climates of the locations these groups inhabited. This idea will be explored through the analysis of postcranial osteometric data in relation to a variety of climate variables. Significant, positive relationships between robusticity and shortened limb length and colder climates would be considered to support this hypothesis.

The keystones of this study are Bergmann's (1847) and Allen's (1877) rules, both of which address adaptive trends in widely dispersed warm-blooded species. Bergmann's rule states that for such species, individuals living in colder climates will have larger bodies than those living in warmer climates. Allen's rule asserts that such species will

also show differences in the lengths of their extremities; individuals in colder climates will have shorter extremities than those in warmer climates. Numerous examples of these rules can be found throughout the animal kingdom (Allee and Schmidt 1951, Rodríguez et al. 2006).

This first chapter serves as a brief introduction to the questions being addressed in this dissertation. Chapter 2 is a review of the literature relevant to the study of climatic adaptation. It is subdivided into sections concerning ecogeographical theory, evidence of climatic adaptation in warm-blooded non-human species, evidence in Old World and New World populations, and other factors affecting biological variation in humans. The last section of chapter 2 explores the literature that has contributed, directly or indirectly, to the question of how much time is necessary for humans to manifest detectable morphological adaptations to climate.

Chapter 3 offers a brief exploration of the process through which the Americas were populated. This chapter proposes a timeline through which biological adaptation in the Americas can be considered. Chapter 4 outlines the materials used in this project, including sample sizes, climate data, and associated dates or archaeological time periods for each site.

Chapters 5, 6, and 7 describe the statistical analyses used in this study. Chapter 5 discusses correlations and regressions between osteometric data and climate variables. Chapter 6 covers the analysis of size and shape variables created from long bone lengths and how these variables can be used to clarify the relationships between long bone length and climate. Chapter 7 attempts to address more complex relationships among the

osteometric and climate variables through multiple regression and canonical correlation analysis.

Chapter 8 explores the question of whether the morphology of the Inuit and Aleut related groups exert an overpowering influence on these data. Many of the same analyses are performed as in chapter 5, but with the exclusion of data from five samples. Chapter 9 compares the patterning of the brachial and crural indices in the New World samples with samples from the Old World. Chapter 10 provides a summary of the results and discusses the findings of this work.

Chapter 2: Literature Review

Bergmann, Allen, and mechanisms of heat production and loss

The theoretical basis for the study of ecogeographical patterning in humans and other warm-blooded animals derives from two classic papers from the 19th century. The earliest of these was Carl Bergmann's study on the relationship between increasing body size and decreasing mean annual temperature within polytypic warm-blooded species (Bergmann 1847, as translated in Katzmarzyk and Leonard 1998). The essential argument of this paper has been distilled into "Bergmann's rule", which states that larger bodied organisms are better adapted to living in cold climates than smaller bodied organisms are, and that the inverse is true in hot climates.

A complementary study on the relationship between climate and extremity form was published three decades later by Joel Allen. Allen argues that the most wide-ranging species are typically the most variable, suggesting that geography has some influence on the anatomy of an organism. The basis of his argument is that in three families of carnivora (candidae, felidae, and procyonidae) there is a tendency toward enlargement of the extremities in those animals living in hot climates (Allen 1877). This theory has similarly been distilled into "Allen's rule", which states that warm-blooded organisms with longer extremities are better adapted to hot climates than those with shorter or smaller extremities are, and vice versa.

The mechanism that governs both of these rules is the relationship between heat loss and heat production (Schreider 1951, Schreider 1975). In situations where a warm-blooded organism is exposed to external temperatures significantly lower than its body

temperature, heat loss through radiation needs to be minimized while heat production through metabolic processes should be maximized. In climates where external temperatures often exceed body temperature, heat loss should be maximized while heat production should be kept to a minimum (Allee and Schmidt 1951).

In climates where warm-blooded animals would most likely experience heat stress, a well adapted organism would produce a minimum of body heat while maximizing the amount of thermolytic surfaces through which heat could be lost through radiation and evaporative cooling. Such an organism would be small bodied and possess large or long extremities, resulting in a high surface area to volume ratio. In cold climates the opposite scenario would be true. A well adapted organism would have a large body and relatively reduced extremities, thus maximizing heat production while minimizing heat loss. The resultant organism would have a low surface area to volume ratio (Allee and Schmidt 1951, Schreider 1975).

Schreider argues that the relationship between the amount of thermolytic surfaces and body mass is more indicative of adaptation to climate than morphology alone. Groups with vastly different average body types but who are both from hot climates, such as native Somalians and indigenous Mexicans, share similar surface area to mass ratios despite their differences in body mass and form (Schreider 1975). Ruff proposes a physiological argument to explain why pygmy groups, all of whom reside in hot, humid climates, do not typically possess long limbs as would be expected with Allen's rule. He argues that linear body forms are adaptive in hot, dry environments where evaporative cooling would function well. The humidity of tropical forests prevents this method of heat loss from operating with much efficiency. Instead of trying to lose heat more easily,

the reduced body size typical of pygmy groups and other small-bodied tropical groups is an adaptation to reduce overall heat production by the body (Ruff 1993, Holliday and Falsetti 1995). These studies show that overall size and extremity size are not the only factors in ecogeographical patterning, but that other morphological variations also may be adaptive.

One specific feature that is often described as an adaptation to climate is the relative length of the distal segments of the limbs. The forearm and lower leg lose heat more rapidly than the upper arm and thigh do due to the formers' larger surface area to volume ratio, so relatively shorter distal limb segments would be expected in cold adapted populations (Holliday 1999). This trait is often described in terms of the brachial and crural indices (i.e. Hall et al. 2004, Porter 1999, Yamaguchi 1989), though it can be assessed through other means (Holliday 1999, Meadows Jantz and Jantz 1999). Populations which are in the process of adapting to colder climates may first exhibit an overall shortening of the limbs, then experience abbreviation of the distal segments (Holliday 1999).

The theoretical basis for Bergmann's and Allen's rules is that climate related patterns in morphology are the result of natural selection acting upon cold and hot temperature stresses (Hall and Hall 1995). In humans, body proportions are typically similar among populations with shared ancestry (Palomino et al. 1979, Rudan et al. 1986, Holliday and Falsetti 1995, Tanner 1976, Katzmarzyk and Leonard 1998), manifesting themselves as early as fetal development (Holliday 1997b) and childhood (Roberts 1978). Konigsberg and Ousley (1995) argued that phenotypic variance in the Boas data is

closely related to genotypic variance, making the analysis of phenotypic traits an acceptable proxy for the examination of genotypic variation.

Body proportions seem to be conservative traits, changing little in spans of time less than 500 years long (Martorell et al. 1988, Palomino et al. 1979, Rudan et al. 1986, Froment and Hiernaux 1984). These statements support two premises of this study: human body proportions are strongly influenced by genetics, and that differences in these proportions among populations are the result of gradual changes brought about by slow-acting natural selection and not the product of temporary changes in physiology (Benoist 1975).

Causes and influences of biological adaptation

A multitude of climatic variables have been examined as possible correlates of ecogeographical patterns. While many studies examine ecogeographical patterning in terms of large scale climate differences, many studies have noted correlations between specific variables and body proportions. Significant associations between body size and/or proportions have been noted for precipitation (Crognier 1981, Hall and Hall 1995, Yom-Tov and Geffen 2006), humidity (Hiernaux and Froment 1976), temperature during the hottest months (Crognier 1981, Hiernaux and Froment 1976, Schreider 1951), temperature during cold months (Johnston and Selander 1971, Newman 1960, Newman and Munro 1955), mean annual temperature (Katzmarzyk and Leonard 1998, Murphy 1985, Newman 1953, Newman 1962, Newman 1960, Newman and Munro 1955, Roberts 1978, Roberts 1953, Stinson and Frisancho 1978), and seasonal differences in temperature and precipitation (Murphy 1985). Similar patterns have also been noted for

latitude (Holliday 1999, Jacobs 1985, Johnston and Selander 1973, Murphy 1985, Ruff 1991), a variable that implies differences in a number of specific measures. The variety of factors that have been found to be associated with patterns in body proportions suggests that such patterns exist in humans, but that these patterns are not easily correlated with one specific measure. Human morphology responds to multiple stresses simultaneously, making it impossible to name a single causative factor for ecogeographical patterning in humans.

It can be very difficult to separate the impact of genetic and nongenetic plastic influences on human morphology (Meadows Jantz and Jantz 1999). This study seeks to minimize the impact of environmental factors by examining skeletal remains from prehistoric and protohistoric times. This approach eliminates the need to consider secular change, gene flow from European and African populations, the impacts of Old World technology, and any possible affects of the continent-wide epidemics that accompanied the first Old World explorers and colonists as causative agents of biological change.

The possible influences of an environment on growth and development are more difficult to remove. The samples used in this study differ in ecological settings and cultural practices. Factors associated with these which can affect human biology include differences in subsistence strategy, disease load, and habitual activity pattern. Using only osteometric variables, it is difficult if not impossible to account for potential differences in nutritional, health, and activity status among these samples. In an attempt to minimize the influence disease and poor nutrition, specimens with notable pathologies were excluded from this analysis. Activity related remodeling of the skeleton is difficult to address, but intergroup differences should be minimal as all samples used in this study

were engaged in some form of subsistence production or acquisition that relied on lithic technology and human labor. Even in socially stratified prehistoric societies, there likely was little difference in habitual activity patterns as inferred from the development of muscle insertion sites between the elites and the rest of the populace (Harle and King 2004), though it should be noted that other authors have argued for status based differences in long bone morphology based on cortical bone thickness (Hatch et al. 1983).

Ecogeographic variation in warm-blooded non-human species

All wide-ranging warm-blooded species are subject to different environmental stresses throughout their ranges. A number of studies have explored the potential effects of ecogeographical patterning in various mammal and avian species. These studies often lend support to Bergmann's and Allen's rules or offer alternative explanations when deviations from these rules are observed. While non-human warm-blooded organisms lack the cultural buffering seen in modern *Homo sapiens*, the environmental stresses experienced by these species are the same stresses humans in that environment would have to cope with, making these studies relevant to an exploration of human biological adaptation.

Johnston and Selander's (1964, 1971) studies of North American house sparrows offer support for Bergmann's rule. The authors also demonstrate that significant adaptive changes can occur in fewer than 115 generations (Johnston and Selander 1971). North American house sparrows derive from a limited stock that was introduced to the continent between 1852 and 1860. Since then they have grown into a large, wide-ranging

population. This species shows a significant amount of morphological variation within its range, following clinal patterns seen in indigenous avian species (Johnston and Selander 1964). Measures of body size and limb length are consistent with Bergmann's and Allen's rules, in that they are negatively correlated with measures of winter temperature, suggesting that size variation in North American sparrows is adaptively organized (Johnston and Selander 1971).

While North American sparrows follow expected patterns of ecogeographic adaptation, European and South American species seem to deviate from this pattern. European birds tend to be smaller in the higher latitudes, which is opposite of the expected trend. Johnston and Selander hypothesize that this is related to the very short feeding days available to high latitude European birds in the winter, making it impossible to gather enough resources to support a large-bodied animal in the amount of time per day available for feeding (1973). South American sparrows show no significant association with latitude, suggesting that stresses unrelated to climate tend to override the effects of the ecogeographical rules (Johnston and Selander 1964).

Murphy's work on European and New Zealand sparrows finds similar deviations from Bergmann's rule, which the author explains as the result of seasonal differences in food availability. Larger animals are better able to survive periods of time without food than smaller ones, making it adaptive to be larger bodied in areas that experience seasonal food scarcity. Across all locations studied, annual temperature range is the most important correlate with body size, even more so that latitude (Murphy 1985).

Studies exploring avian skeletal biology are not consistent in supporting or contesting ecogeographical rules. Many species of birds possess adaptations to cold,

including heavier plumage, increased heat insulation, and metabolic differences, that would not be manifested in the skeleton (Kendeigh 1969). Additionally, birds may experience heat loss more acutely in areas of their bodies unprotected by feathers, such as the tarsi and feet. In western red-tailed hawks, cold adaptation may not be seen in body size or proportions, but in feather density. This species also experiences water stress in parts of its range, which may lead to anatomical changes that would seem to be maladaptive when temperature is the only environmental factor considered (Fitzpatrick and Dunk 1999).

Like Kendeigh, McNab argues that Bergmann's rule is only effective if ample food resources are available to sustain a larger body in a cold climate. In a survey of widespread mammal species, the author finds that only 32% of the species conform to Bergmann's rule. Instead of climate being a significant factor in determining body size, McNab argues that size is more closely associated with the size of available prey or food (1971).

Yom-Tov and Geffen (2006) argue that mean annual rainfall is a significant correlate of body size, which is especially pertinent in drier desert and semi-desert environments, where rainfall greatly impacts resource availability. In a study of 17 mammal species from the Levant, the authors found that mean annul rainfall was a better predictor of body size than temperature, with the former explaining an average of 30.8% of the variance in size and temperature explaining 12.3% of the variance. In approximately half of the cases in which body size was related to temperature, the relationship was counter to what Bergmann's rule predicted.

Several other recent studies document trends in body size that conform to Bergmann's rule. Storz et al. (2001) argue that clinal variation in body size in *Cynopterus sphinx*, a fruit bat from the Indian subcontinent, follows a temperature gradient. Cerulean warblers (*Dendroica cerulea*) in eastern North America also conform to Bergmann's rule, with populations in the northern part of the species range being larger than populations from further south (Jones et al. 2005). Bergmann's rule and adaptation to thermoregulatory stress also appear to affect body size in the gray mouse lemur (*Microcebus murinus*) (Lahann et al. 2006).

The literature on warm-blooded non-human species illustrates several points relevant to the study of climatic adaptation in human skeletal remains. Biological adaptation can occur in a manner that will not manifest in the skeleton, such as feather density (Fitzpatrick and Dunk 1999, Kendeigh 1969), metabolic rates (Kendeigh 1969), and body composition (Kendeigh 1969). Deviations from the expectations of Bergmann's and Allen's rules often can be explained by adaptation to more crucial stresses (Johnston and Selander 1964), such as food availability (McNab 1971, Kendeigh 1969, Yom-Tov and Geffen 2006) and water scarcity (Fitzpatrick and Dunk 1999).

Ecogeographic variation in Old World Homo sapiens

While Bergmann's and Allen's rules do not always apply to non-human warm-blooded animals, they may affect human morphology to a great extent. The large body size of humans makes identifying variation easier. We have the largest geographic range of any species and large samples are available for study from throughout the entire geographic range. Trends that are difficult to identify in other species may be more

readily visible in humans (Newman 1953). While cultural buffering against climate conditions should be considered as a factor that might have reduced the need for biological adaptations, it can be argued that the cultural adaptations that allowed humans to cope with climate conditions actually contribute to the ecogeographical variation seen in humans. Without adaptations such as fire, food preservation, and tailored clothing, it would be unlikely that humans would have expanded into previously inhospitably cold climates and thus would not have had the opportunity to evolve biological adaptations to them (Ruff 1991).

Homo sapiens in the Old World represent the maximum amount of ecogeographic variation seen in modern humans. Humans have inhabited Africa, Europe, and Asia millennia longer than humans have lived in the Americas. Old World populations demonstrate the extremes of human adaptation to climate, from hot and dry Sub-Saharan Africa to extremely cold regions of northern Europe and Asia. By examining what ecogeographical patterns exists in the Old World, predictions for such adaptation can be made for populations in the Americas.

Perhaps the largest studies in ecogeographical patterning in the Old World were conducted by D.F. Roberts. The author identified a correlation between weight and mean annual temperature, with a tendency for the individuals with the highest weights to be from cold climates and those with the lowest weights to be from warm climates (Roberts 1953). He also noted relationships between high basal metabolic rate and cold stress, relative sitting height and mean annual temperature, increased calf length and reduced calf circumference and heat stress, decreased upper limb and forearm length and cold

climates, and increased chest girth, biacromial breadths, and bi-iliac breadths in cold climates (Roberts 1978)

Katzmarzyk and Leonard (1998) reexamined many of the same groups used by Roberts in his 1978 analysis using data from studies published after 1953. The authors found many of the same patterns as Roberts, including an inverse association between body mass and body mass index with mean annual temperature, a positive correlation between the surface area to body mass ratio and temperature, and a negative correlation between relative sitting height and temperature. The correlations in this study are not as high as they were in Robert's 1978 study, which the authors attribute to modernization in developing countries and a subsequent increase in body mass (Katzmarzyk and Leonard 1998).

Crognier examined morphological patterns in anthropometric variables taken on peoples from Europe, the Middle East, and North Africa. The author found support for Bergmann's and Allen's rules, documenting increases in temperature related to a decrease in general body size. The most significant correlations with cranial and postcranial anthropometric variables were with rainfall in the driest month and temperature in the hottest month. On average, climate factors explain 35% of the variation in anthropometric measurements for these groups, meaning that about 65% of the variation is unrelated to climate (Crognier 1981).

Ecogeographical patterns appear to exist regardless of the technological development of the groups from which the study samples derive. Schultz (1937) examined several anthropometric indices in what were described as "civilized and uncivilized races of man". The author found that groups from warmer climates tended to

have higher crural indices than other groups and that the samples from colder climates had lower brachial indices than other groups (Schultz 1937).

In addition to anthropometric studies, several investigators have explored this question through the use of osteometric data. Holliday (1997a) has explored body size and proportions among modern and Pleistocene Old World skeletal samples. For modern samples, there is a significant negative correlation between the brachial and crural indices and latitude, supporting Allen's rule. Higher latitude groups also tend to have larger femoral heads and shorter humeri and tibiae relative to trunk height (Holliday 1997a). Ruff has demonstrated that a worldwide sample conforms to Bergmann's rule by measuring reconstructed bi-iliac breadth. As predicted, bi-iliac breadth is greater in cold climates and smaller in hot locations (Ruff 1991).

The influence of climate on anthropobiological variables can be seen within the confines of a continent. Hiernaux and Froment (1976) compared climate variables to anthropometric measurements, blood group data, and fingerprint data for 460 Sub-Saharan African groups. The authors found that stature and nose shape followed expected patterns, with stature being greatest in the areas which are the warmest, rainfall is the least, and seasonal differences in humidity were the greatest (Hiernaux and Froment 1976). Significant north-south differences within the European Mesolithic for the brachial, crural, and claviculo-radial indices have also been documented (Jacobs 1985, 1993), as have significant differences in the brachial and crural indices among three geographically defined groups of Jomon (Yamaguchi 1989). These studies support the idea that geographically restricted samples can demonstrate morphological variation in association with climate variation.

There is overwhelming support for ecogeographical patterns of human variation in the Old World. While it is important to note that climate differences cannot explain all variation between groups (Roberts 1978, Crognier 1981), it should also not be discounted as a significant influence on human morphology. The strength of these patterns also suggests that cultural buffering does not negate the need for populations to adapt to their environments through biological means.

Ecogeographical variation in New World Homo sapiens.

The relatively recent colonization of the Americas by *Homos sapiens* presents a unique natural experiment in which to examine human adaptation to climate. Significant populations of humans were likely dispersed throughout the Americas by 11,500 RCYBP as evidenced by the establishment of the widespread, archaeologically visible Clovis sites (Haynes 2002). The indigenous populations of the Americas demonstrate the amount of biological adaptation that a group can undergo in less than 13,500 years.

Newman (1953) has done extensive work on this topic with New World populations. The author has documented patterns of anthropometric variables in the indigenous populations of the Americas that appear to follow ecogeographical rules, though not necessarily in the smooth clinal distributions seen in the Old World. Among his findings is a trend in average male stature, where the shortest peoples are concentrated in lower latitudes and stature increases as latitude increases. This is contrary to the patterns seen in Boas's data, in which stature is positively correlated with mean annual temperature (Jantz et al.2007). Newman also records that the reduced stature of Western Eskimo groups is due to shortened legs, as their sitting height is

similar to that of the tallest American Indians. Newman argues that these patterns of variation are too closely associated with climate variables not to be the products of adaptive changes since the peopling of the Americas.

Body weight in living American Indians also seems to follow clinal patterns. For a sample of 60 adults, Newman (1960) found that body weight is negatively correlated with mean annual temperature and mean temperature of the coldest month, the latter being the stronger relationship. The author argues that body weight is the significant ecological correlate in humans, with 50% of variation in this trait being attributable to mean temperature of the coldest month. When stature is held constant, the correlation between weight and temperature remains statistically significant; when weight is held constant, stature and temperature demonstrate no significant relationship (Newman 1960).

Newman (1962) has also examined morphological patterns in prehistoric American Indians as evidence of evolutionary change. Using stature estimates and the cranial index, Newman argues that prehistoric North Americans experienced changes in average stature that correlate with local climate conditions. The changes are not related to health or nutrition advances or setbacks, as shorter groups have evolved from taller ones and vice versa. Newman documents a clinal pattern for stature in North America, but argues that the pattern only exists because of stature's strong correlation with body mass, which he considers the ecologically responsive feature.

Anthropometric data has been used to examine morphological variation in the New World. Hall and Hall used data collected by Boas a century earlier to explore climate adaptation in the Pacific northwest. The authors found that individuals who lived

in areas that experienced more rainfall had larger trunks and shorter legs than those from drier climates. They argue that this is support for Bergmann's rule, as higher rainfall is associated with cooler summer temperatures in this region (Hall and Hall 1995).

Katzmarzyk and Malina used anthropometric data to examine differences between the Temagami, an Ojibwa group, and a European-Canadian sample. Among the females, the Temagami had higher body masses and wider skeletal breadths despite being similar in stature and relative sitting height to the women of European ancestry. The authors argue that the difference in mass has little to do with adaptation to climate, but is instead the product of a secular trend (a trend found in a modernized population that is usually attributable to a stable food supply, access to and improvements in healthcare, and other) toward higher body masses within First Nations populations (Katzmarzyk and Malina 1999).

Osteometric data from even the smaller parts of the postcranial skeleton can be used to examine ecogeographical rules. Lazenby and Smashnuk examined the 2nd metacarpal in a sample of prehistoric Inuit for evidence of cold adaptation. The authors argue that the hands should show ecogeographical patterning, as they would likely often be exposed to the cold. Compared to a sample of European ancestry, the Inuit metacarpal is shorter and broader, as would be expected if Allen's rule were in effect (Lazenby and Smashnuk 1999).

Arguments against adaptation to climate

Climate conditions are not the only selective pressures to which human populations are subject. Stresses related to biomechanics, subsistence patterns,

differential nutritional and health statuses, secular change, and allometric relationships among anthropometric and osteometric measurements are also offered as explanatory factors for patterns of morphological variation. These factors can influence anatomy through altering growth and development trajectories. Several studies have explored their relative importance in explaining the patterning of human variation.

Biomechanical efficiency is often cited as factor affecting human body proportions, especially in studies where evidence for climate adaptation is lacking (Porter 1999, Frayer 1981). The most basic argument in this area is for maximizing locomotor efficiency. An increase in stature or a decrease in the diameter of a long bone will decrease the power expenditure necessary for locomotion (Wang and Crompton 2003), features which also describe the expected morphological adaptations to heat stress. Individuals with longer legs have increased stride lengths which increases locomotor efficiency.

Long legs would be especially advantageous to individuals in highly mobile populations as they allow for a longer stride length with little increase in the energy necessary to move them (Wang and Crompton 2003). Holliday and Falsetti (1995) test this hypothesis by examining body proportions in modern hunter-gatherer groups. The authors find that there is no significant relationship between how mobile a group is and lower limb length. They do find that temperature and precipitation are associated with limb length within these groups (Holliday and Falsetti 1995).

It should be noted that limb length cannot increase indefinitely or in the absence of changes in the rest of the body. Limb bones must remain robust enough to tolerate the bending forces placed on them by locomotion (Wang and Crompton 2003) and the trunk

must be massive enough to withstand the oscillation caused by the changes in velocity experienced by a limb in movement (Witte et al. 1991).

Another potential biomechanical influence on morphology is that certain body types are more efficient users of specific technologies. One possibility is that differences in technology use have influenced the development of body proportions in prehistoric and historic human populations. How efficiently an individual can use a weapon is dictated by body build, which should be under strong selective pressure as it is strongly associated with survival and future reproductive success. Brues's (1959) "spearman and archer" hypothesis argues that individuals with linear builds are the most efficient users of spears while those with more laterally expanded bodies are efficient archers. The adoption of archery may have lead to the physical specialization for maximum efficiency with this type of weapon. The use of the sling as a weapon has also been considered as an influence on body proportions by Wells (1960), who argues that long forearms in Neolithic and Iron Age European skeletons could be an adaptation to the efficient use of this weapon. These theories are not necessarily alternatives to climatic adaptation, but should be considered as a possible contributing factor to morphological variation (Brues 1959).

Frayer employs Brues's hypothesis to explain differences in body proportions between the European Upper Paleolithic and Mesolithic. Upper Paleolithic groups used spear technology, which should be associated with increased statures and long limbs. Mesolithic people used the bow and arrow, which should be associated with shorter statures and reduced arm length. Frayer states that these patterns are present in prehistoric skeletal remains from these periods. The author argues that these patterns are

the opposite of what would be expected for climate adaptation, as the climate as warmer during the Mesolithic than the Upper Paleolithic (Frayer 1981).

Habitual activity patterns can potential alter morphology, especially diaphyseal robusticity in long bones (Pearson 2000). However, use-related changes in long bone morphology builds upon a morphological pattern previously established by other factors, including genetics (Trinkaus et al. 1999). A study of two groups of Fuegans does not support the idea that subsistence strategies can effect skeletal dimensions in such a way as to obscure or complicate adaptation to climate. Pearson and Millones (2005) document that a group of coastal fisherman who utilize canoes and a group of terrestrial hunter-gatherers do not demonstrate activity related differences in skeletal robusticity.

Changes in nutritional status can lead to an increase in limb length, and thus, stature (Ruff 2002). This can effect the limb as a whole, or can impact the distal limb segments more significantly than the proximal ones (Meadows and Jantz 1995, Meadows Jantz and Jantz 1999). Froehlich (1970) documents changes in stature within three generations of Japanese-Americans, with the first generation being immigrants from Japan and the latter two being American-born. Between the first and second generation there was a 10.62 cm increase in average stature for males and a 4.17 cm increase for females. The males showed no further increase between the second and third generations, while the females had an increase of 3 cm.

Tanner et al. (1982) document a parallel secular trend in stature in Japan. Between 1957 and 1977, average adult stature increased by 4.3 cm for males and 2.7 cm for females. Average sitting height for this sample did not change, suggesting that the increase in stature is due to an increase in leg length (Tanner et al. 1982). This change

alters the relationship between leg length and stature in the absence of an increase in temperature, which is counter to the expectations of Allen's rule.

The influence of secular trends in body proportions is further documented by examining differences between Japanese children and American-born children of Japanese descent. In the 1950s, Greulich documented that Japanese-American children in California were taller, heavier, more skeletally advanced, and possessed longer legs than their cohorts in Japan, which he attributed to the more favorable environment in California for growth and development. However, by 1970, the differences between the two groups were greatly reduced as Japan recovered economically from World War II (Greulich 1976). Such dramatic changes in body proportions within generations cannot be attributed to genetic factors, indicating that adaptation to climate is not the only factor that can influence body proportions.

Limited nutritional availability can also impact stature and body size due to smaller bodies having reduced caloric requirements. Shea and Bailey (1996) argue that this contributes to the short statures of pygmy groups, not an alternative form of heat adaptation. The authors argue that the seemingly maladaptive body size and proportions in these groups is the result of ontogenetic effects on allometry that originate with nutritional deficiency (Shea and Bailey 1996).

Nutrition's impact on limb length may not be so great as to mask underlying climate adaptations. The populations with the relatively longest legs live in tropical developing nations where nutritional availability and other environmental factors may be less than ideal (Ruff 1993). Highland and lowland Quecha groups also demonstrate a pattern that is consistent with ecogeographical adaptation and counter to nutritional

predictions. The highland group, which experiences cold stress, is largely better nourished than the lowland group. The lowland group has relatively longer legs, consistent with a warmer climate but inconsistent with the idea that better nutrition results in longer limbs (Stinson and Frisancho 1978).

Allometry and secular change also may complicate studies of morphological variation in response to climate. Meadows and Jantz (1995) document a positive allometric relationship between the bones of the lower limb and stature in males from the Terry collection and World War II fatalities. The authors also argue that there is a secular trend toward increased combined femur and tibia length and in the tibia/femur ratio between 1840-1970.

The results of physiological stress potentially could mirror adaptive patterns. Serrat el al. (2007) argue that effects mirroring Allen's rule can be induced in mice. The authors reared two samples of mice at two different ambient temperatures. As adults, the mice reared in the cooler temperature exhibited reduced ear size and shortened tail lengths that would be expected if the animals were adapted to a specific climate. Serrat et al. argues that the cooler temperature results in a reduced blood flow to the extremities, resulting in patterns that could be mistaken for those predicted by Allen's' rule (2007).

How long does it take for ecogeographical patterns to evolve?

Have the Americas been populated for long enough for ecogeographical patterns to have evolved? The preceding literature documents that clear, clinal patterns are visible in the Old World. Such patterns also are argued for in much of the literature on New World samples, but the relationships between body proportions and climate variables

may be more ambiguous as those in the rest of the world. North American house sparrows have experienced significant morphological differentiation rapidly, in a span of 50 to 115 generations (Johnston and Selander 1971). Are humans capable of adapting as rapidly, or does our species evolve at a slower rate?

Gradual genetic-based changed in morphology in response to climate does not appear to occur among humans in a time spans less than a millennium, or 25 to 50 generations assuming generations between 20 and 40 years in length. This excludes situations in which major selection events resulted in a drastically altered and reduced gene pool, as is suspected occurred during the peopling of the Pacific islands. Body proportions seem to be a conservative trait, as demonstrated by differences in the average sitting height to stature ratio between African-American children and European-American children (Martorell et al. 1988). Similar patterns can be seen in Chile, with individuals of Amerindian ancestry from varying altitude zones more closely resembling each other than their neighbors of Spanish ancestry (Palomino et al. 1979). The climatically homogenous island of Hvar offers another example of this phenomenon. It is home to two distinct and reproductively isolated groups which, despite 10 to 15 generations of residence in virtually identical climates, maintain body proportions closer to those of their ancestral groups than to those of their neighbors (Rudan et al. 1986).

While the pace of human adaptation may not occur at detectable levels within a few centuries, it still may proceed at a somewhat rapid pace, taking only a few thousand years to evolve. Change in body proportions from the seemingly warm adapted anatomically modern humans of the European Early Upper Paleolithic to the more cold adapted forms of modern Europeans occurred in 15,000 to 20,000 years, with modern

patterns of body proportions emerging during the Middle Upper Paleolithic (Holliday 1997b, Trinkaus 1997). Hulse (1960) argues that human adaptation is not a rapid process. Hulse argues that the process of climate adaptation takes longer than 20,000 years to occur, citing this as the reason for a lack of traditional warm climate morphology patterns in the equatorial regions of the Americas (1960). However, this argument does not consider the differences in humidity and rainfall between the equatorial Old World and New World, only their similarity in latitude.

Other investigators argue that humans have been in the Americas long enough for significant adaptation to climate to evolve. Newman (1962) argues that the range in mean male statures seen in the New World is too wide to be indicative of anything but genetic adaptation. Pearson and Millones argue that the settlement of the Americas occurred long enough ago for adaptation to climate to have taken place in the locations most distant from Beringia, Tierra del Fuego. The authors demonstrate that two Fuegan groups have very robust limb bones and relatively broad pelves, with values similar to those found in Inuit and Sami samples (Pearson and Millones 2005).

Conclusion

The ecogeographical literature provides several inferences that will be explored and discussed in this study. Morphological variation among prehistoric American Indians and First Nations peoples should demonstrate some relationship with climate variables. These relationships may not be as strong or obvious as those seen in Old World populations, depending on the length of time necessary for adaptation to climate to reach the levels seen in Africa, Asia, and Europe. Patterns may be related to heat stress,

cold stress, precipitation, annual temperature range, latitude, or any combination of these variables. Abbreviation of the distal segments of the limbs may or may not be present, depending on the time depth necessary for these patterns to develop and if this feature is a true ecogeographical correlate.

Chapter 3: The origins of the indigenous populations of the Americas

Direct Evidence: Archaeology

In order to explore questions about the biological adaptations of modern American Indians, it is necessary to investigate the processes of the peopling of the Americas. There is much debate about the number of migrations and the timing of those migrations. In the context of this work, it is necessary to establish a feasible timeline for the latest possible entry in the Americas, as this would establish the minimum amount of time indigenous groups have been subjected to the climatic patterns of the New World.

The earliest evidence of human habitation in the Americas comes from a handful of pre-Clovis sites, all of which have produced radiocarbon dates earlier than 11,500 RCYBP (Goodyear 2004, Dillehay 1997). While there is some debate about the veracity of pre-Clovis claims (i.e. Beaton 1991, Haynes 2002), the antiquity of one of these sites, Monte Verde II in Chile which dates to 12,000-12,500 calBP, has been evaluated and accepted by a team of prehistoric archaeologists. A late Pleistocene occupation of Monte Verde, 16,000 kilometers from Beringia, implies an earlier colonization of the Americas than was previously accepted (Meltzer et al. 1997, Dillehay 1989, 2000).

In the context of biological anthropology in the Americas, the proposed antiquity of the pre-Clovis sites is irrelevant if the early colonizers were not the ancestors of the later American populations. The low archaeological visibility of pre-Clovis sites (Beaton 1991) suggests that these sites might reflect early "failed migrations" into the North and South American continents by groups too small or too geographically distant to establish large population levels (Meltzer 1989). A more conservative estimate for the

immigration of the founding populations of the Americas would be 11,500 RCYBP when the first Clovis sites were occupied and shortly before the widespread dispersal of Clovis technology over the North American continent (Haynes 2002), which only would have been possible if a dramatic increase in population occurred around this time, or if there previously was a large population residing in North America.

Indirect Evidence: Biological and Linguistic Anthropology

Biological and linguistic anthropological analyses have also been used to explore the colonization of the Americas and the origins of the first migrants. Several analyses of mutations in mitochondrial DNA have suggested that colonization of the Americas occurred before the last glacial maximum (Schurr 2004, Torroni et al. 1994), while other support a short chronology (Hey 2005, Schurr and Sherry 2004, Greenberg et al. 1986). Studies utilizing the non-recombinant portion of the Y chromosome also have produced similarly contradictory results (Schurr 2004, Zegura et al. 2004). One complication of using accumulated mutations in DNA to estimate the time the Americas were populated is the unreliability of the "molecular clocks" used to in these estimations (Merriwether 2002). Despite the relatively rapid accumulation of mutations in mitochondrial DNA, estimates about population divergence for the 10,000 to 30,000 year range of interest for the peopling of the Americas can vary widely.

DNA has also been used to investigate the number of migrations into the Americas. Support has been found for one migration into the Americas (Zegura et al. 2004, Merriwether et al. 1996), two separate migrations for the ancestors of most American Indians and the Na-Dene speaking groups (Schurr and Sherry 2004, Torroni et

al. 1994), three migrations consisting of the first migrants, the Na-Dene groups, and the Eskimo-Aleut groups (Greenberg et al. 1986), which is also supported by dental anthropological studies (Turner 1983, Ossenberg 1994) and an unspecified number of multiple migrations (Schurr 2004).

Changes in language and the emergence of language families also have been utilized to examine the number of migrations and the timing of those migrations. Like the genetic studies, the linguistic studies have also produced contradictory results. Greenberg et al. (1986) support a short chronology with three waves of migration, while Nichols (2002) supports a date for colonization around 20,000 years before present and concedes the possibility of subsequent migrations. Nichols refrains from making a decisive statement on the number of migrations into the Americas, arguing that the nature of language development precludes making such a statement with any certainty (2002).

Biological and linguistic anthropology can provide maximum estimates for the peopling of the Americas, but alone they cannot be used to establish the antiquity of humans in the Americas (Zegura et al. 2004). A second concern is that biological and linguistic studies can only estimate time since the ancestors of modern American Indians diverged from their parent groups. These studies cannot tell us if these divergences occurred in the ancestral homeland or after the immigration to the Americas (Meltzer 1989).

It should be noted that biological and linguistic anthropology should be conferred supporting status in the investigation of the timing of the colonization of the Americas. The only way to determine the timing of entry of people into the Americas is to do archaeological investigations in the Americas (Meltzer 1989); the oldest accepted

archaeological site would establish a minimum time since the Americas were first populated. Earlier occupations could have existed and left no archaeological signature that has been found to date, but it should not be supposed that large-scale occupations existed without the evidence to support this hypothesis.

The identification of possible ancestral populations

Biological anthropology has made significant contributions to the identity of the first Americans. Several genetic studies have postulated a relationship between American Indians and the present-day inhabitants of central and northeastern Asia, including regions in Mongolia, Manchuria, and/or southeastern Siberia (Merriwether et al. 1996, Torroni et al. 1993b), Tibet (Torroni et al. 1994) and, in part, coastal East Asia (Torroni et al. 1993a).

Craniometric and osteometric analyses have also contributed to the question of origins of the first Americans. Jantz and Owsley (2004) demonstrated that early American crania most closely resemble Pacific rim groups, which is supported by postcranial evidence from the early Holocene skeletons suggesting that the earliest migrants were adapted to temperate, or possibly even tropical, climates (Hall et al. 2004).

Clear ancestor-descendent population continuity between early Holocene burials and later groups cannot be assumed due to their overall lack of affinity with more recent American Indian crania (Jantz and Owsley 2001). Two possible scenarios must be considered: these few early Holocene burials are members of the ancestral population of the Americas, but have not yet developed the cranial shapes seen in their descendents; or,

these burials are representative of individuals or groups that did not make a significant contribution to the gene pool of modern American Indians.

Discussion

For the purposes of investigating the biological adaptation to climate seen in American Indians, we must be concerned not with the earliest occupation of the Americas, but with the earliest occupation that led to population expansion and divergence. Considering the archaeological, biological, and linguistic data available, I have decided to use the date 11,500 RCYBP, or approximately 13,500 cal BP (Stuiver et al. 2005), the approximate date of the earliest Clovis culture sites (Humphrey and Ferring 1994, Fiedel 2004), as the starting point for the large-scale settlement of the Americas. While it is noted that there are no human biological remains associated with Clovis period, the extensive collection of unambiguous artifacts and sites associated with this period strongly suggests the presence of a large, widespread population. No assumption will be made about the climatic adaptations seen in the first migrant to the Americas, as the founding population(s) may have been indigenous to either the cold climate of Siberia and Beringia in the late Pleistocene, or temperate or tropical climates, following Hall et al. (2004). Evidence of the development of morphology associated with climate stresses specific to the region from which a sample derives will be considered as supporting biological adaptation to climate.

These assumptions are not intended to discount the validity of pre-Clovis sites or arguments for early of multiple migrations, but are intended to serve as an admittedly conservative starting point for the divergence of the first American populations. Pre-

Clovis peoples are not considered in this study due to the lack of any human biological remains from this time period (Greenberg et al. 1986), though it should be noted that while there are many Clovis culture sites, there are no known human remains from this period either. The possibility of multiple migrations should not impact the analysis greatly, as estimates of times of these later migrations likely occurred before 9000 BP (Turner 1983), or at the latest, 4000 BP for the Eskimo-Aleut (Greenberg et al. 1986), who in their migration to the Americas most likely did not experience dramatic changes in climate (Ossenberg 1994).

Chapter 4: Bioarchaeological Samples and Climate Data

The samples used in this study are from two sources, those measured by the investigator at four institutions and those collected by the Office of Repatriation at the Smithsonian Institution National Museum of Natural History. Sites were chosen in an effort to sample from a wide geographic range (see Figure 4.1). Sites were also temporally restricted to strengthen the validity of intersite comparisons. Table 4.1 provides the approximate dates or time periods for the sites used in this analysis and the references from which these dates or time periods were obtained. All sites used in this analysis date within a 3500 year range, with the majority (21 of 25) having no component older than 1500 years. The majority are prehistoric, with the latest component of any site dating to 1830 AD.

Only skeletally mature individuals were used in this study. An individual was excluded from the study if the proximal epiphysis of the humerus was not, at the minimum, in the process of fusing to the diaphysis. Several individuals whose humeri showed complete fusion had unfused sternal epiphyses of the clavicles. In such cases the long bones were measured, but the clavicles were not.

The sex of the individuals measured by the investigator was estimated from gross morphological features of the os coxae. If the os coxa was unavailable, poorly preserved, or the features were ambiguous, sex was assigned using the vertical head diameter of the humerus or the epicondylar breadth of the humerus. In the rare event that neither the os coxae nor the humerus were available or well preserved, gross morphological features of



1. Kauwerak
2. Mummy Caves
3. St. Michael
4. Umnak Island
5. Prince Rupert Harbour
6. Steuben
7. Fort Prince of Wales
8. Souris Valley
9. Bussinger
10. Huron Village
11. Juntunen
12. Edwards Mound
13. Lake George
14. Bell-Philhower
15. Hawikku
16. Kwastiyukwa
17. Pueblo Bonito
18. Native Point
19. Madisonville
20. Turpin
21. Sully
22. Dr. Jarman
23. Thompson Village
24. Toqua
25. Berrians Island

Figure 4.1. Locations of archaeological sites.

Table 4.1 Bioarchaeological samples used and associated dates.

Site	Approximate Dates	Source	Museum
Alaska			
Kauwerak	Late PREH[1]	Giddings 1964	NMNH[6]
Mummy Caves	Late PREH/Early HIS[2]	Hrdlicka 1941	NMNH
St. Michael			NMNH
Umnak Island	1000 BC – Early HIS	Laughlin 1962	NMNH
British Columbia			
Prince Rupert Harbour	1550 BC-450 AD	Cybulski 1992	CMC[7]
Illinois			
Steuben	Middle WL[3](Hopewell)	Schoenbeck 1948	UMMA[8]
Manitoba			
Fort Prince of Wales	HIS	Nash 1970	CMC
Souris Valley	Late PREH-PROH[4]	Capes 1963	CMC
Michigan			
Bussinger	Early-Late WL	UM NAGPRA	UMMA
Huron Village	Early-Late WL	UM NAGPRA	UMMA
Juntunen	1100-1650 AD	Brashler et al. 1999	UMMA
Mississippi			
Edwards Mound	Late PREH/PROH	Starr 1992	PMHU[9]
Lake George	700-1200 AD	Kidder and Fritz 1993	PMHU
New Jersey			
Bell-Philhower	Late PREH-Early HIS	Ritchie 1949	NMNH
New Mexico			
Hawikku	1200-1600 AD		NMNH
Kwastiyukwa	Late PREH-Early HIS	Barrett 2002	NMNH
Pueblo Bonito	890-1140 AD	Howell and Kintigh 1996	NMNH
Nunavut			
Native Point	1st century AD-HIST	Giddings 1964, Taylor 1960	CMC
Ohio			
Madisonville	1000-1700 AD	Griffin 1992	PMHU
Turpin	1000-1250 AD	Griffin 1992	PMHU
South Dakota			
Sully	1600-1830 AD	Owsley and Jantz 1978	NMNH
Tennessee			
Dr. Jarman	MIS[5]	Peabody inventory	PMHU
Thompson Village	Late MIS	McClung inventory	MMUT[10]
Toqua	1300-1600 AD	Polhemus 1987	MMUT
Washington			
Berrians Island	1750-1810 AD	Newman 1957	NMNH

[1]PREH – prehistoric, [2]HIST-historic, [3]WL-Woodland, [4]PROH-protohistoric, [5]MIS-Mississippian
[6]NMNH – Office of Repatriation, National Museum of Natural History, Washington, DC
[7]CMC – Canadian Museum of Civilization, Hull, Quebec
[8]UMMA – University of Michigan Museum of Anthropology, Ann Arbor, Michigan
[9]PMHU – Peabody Museum of Archaeology and Ethnology, Harvard University, Cambridge, Massachusetts
[10]MMUT – Frank H. McClung Museum, University of Tennessee, Knoxville, Tennessee

the cranium and mandible were used to estimate sex (Bass 1995). If none of these elements were present, the individual was not used in this study.

Most of the skeletons used in this study were from individual burials. Multiple burials that contained more than one adult were not used in this study. If a multiple burial included one adult and any number of subadults, the adult was considered for inclusion. Elements that showed significant pathologies that would impact measurements, including osteomyeletis, poorly set antemortem fractures, and bowed long bones, were not used in this analysis.

The skeletal materials available for study were often subject to preservation issues. Measurements were only taken if no exfoliation of the cortical bone had occurred. Fragmentary bones were used only if they could be reassembled and no parts essential to taking the measurement were absent. Due to these restrictions, it was not possible to take all of the 29 bilateral measurements on any of the skeletons used.

Table 4.2 gives sample sizes for the 25 samples used in this analysis, categorized by state or province. Two of these samples, Souris Valley and Prince Rupert Harbour, are composites of several smaller sites from the same geographic area which date to the same time periods (Capes 1963, Cybulski 1992).

Table 4.3 lists the postcranial measurements used in this analysis. Most of the measurements were taken as described in the Standard for Data Collection from Human Skeletal Remains (Buikstra and Ubelaker, eds., 1994). Three other measurements were taken but dropped from the analysis: bi-iliac breadth and radius distal epiphyseal breadth, which were not available in the data obtained from the Smithsonian Institution's Office

Table 4.2. Sample sizes and sex distribution.

Site	Total individuals	Males	Females
Alaska			
Kauwerak	21	13	8
Mummy Caves	37	20	17
St. Michael	27	14	13
Umnak Island	20	11	9
British Columbia			
Prince Rupert Harbor	35	28	7
Illinois			
Steuben	17	11	6
Manitoba			
Fort Prince of Wales	2	1	1
Souris Valley	19	15	4
Michigan			
Bussinger	8	5	3
Huron Village	5	4	1
Juntunen	23	15	8
Mississippi			
Edwards Mound	4	3	1
Lake George	3	2	1
New Jersey			
Bell-Philhower	34	18	16
New Mexico			
Hawikku	137	56	81
Kwastiyukwa	72	23	49
Pueblo Bonito	33	11	22
Nunavut			
Native Point	52	28	24
Ohio			
Madisonville	64	32	32
Turpin	10	7	3
South Dakota			
Sully	148	83	65
Tennessee			
Dr. Jarman	19	10	9
Thompson Village	8	3	5
Toqua	33	16	17
Washington			
Berrians Island	23	14	9
Totals	854	443	411

Table 4.3. Measurements used in this analysis.

Element	Measurement
Humerus	maximum length
	maximum diameter at midshaft
	minimum diameter at midshaft
	maximum vertical head diameter
	epicondylar breadth
Radius	maximum length
	medial-lateral diameter at midshaft
	anterior-posterior diameter at midshaft
	maximum head breadth
Clavicle	maximum length
	superior-inferior diameter at midshaft
	anterior-posterior diameter at midshaft
Femur	maximum length
	bicondylar length
	anterior-posterior diameter at midshaft
	medial-lateral diameter at midshaft
	circumference at midshaft
	maximum head breadth
	anterior-posterior subtrochanteric diameter
	medial-lateral subtrochanteric diameter
	epicondylar breadth
Tibia	maximum length
	maximum proximal epiphyseal breadth
	maximum distal epiphyseal breadth
	maximum diameter at nutrient foramen
	medial-lateral diameter at nutrient foramen
	circumference at nutrient foramen
Os Coxa	maximum length
	iliac breadth

of Repatriation, and wrist breadth, which was not measurable on most skeletons as it requires a complete paired ulna and radius, and was not readily replicable. The original data collected for this study is on file at the individual institutions where the data was collected.

The 29 measurements used in this analysis were selected due to their potential to be informative about ecogeographical adaptation. Measures of the epiphyseal size, such as head diameters and epicondylar breadths, are associated with limb thickness. More robust limbs have a reduced surface area to volume ratio compared with slender limbs. Diaphyseal diameters are also associated with limb thickness in a similar manner. Measures of the length of the limb bones are related to the length of the segments of the extremities. Longer extremities increase the surface area to volume ratio of the limbs, providing more thermolytic surfaces through which to facilitate heat dissipation. This is particularly true for the distal segments of the limbs, which are more slender than the proximal segments. An increase in the length of the distal segments increases the surface area to volume ratio more rapidly than an equivalent increase in the proximal segments does.

The above measurements will be analyzed in conjunction with climate variables from the 25 archaeological sites used in this analysis. All of the sites in this study date to the last one-third of the Holocene. While there have been minor temperature fluctuations within this epoch, these dates are recent enough that modern climate data is valid (Jacobs 1985). Information for sites in the United States was obtained from the National Climatic Data Center (National Oceanic and Atmospheric Administration et al. 2002). Climate information for the Canadian sites was obtained from the Meteorological Service of

Canada's National Climate Archive (Meteorological Service of Canada, Environment Canada 2002). These publications provided data for mean January temperature, mean July temperature, mean annual temperature, and mean annual precipitation data compiled between 1971 and 2000. Annual temperature range was calculated as the difference between mean July temperature and mean January temperature. Values given in Fahrenheit and inches were converted to Celsius and millimeters. Climate data for each site is provided in table 4.4.

Table 4.4. Climate variables by site.

Site	Annl Temp	Jan Temp	July Temp	Annual Precipitation	Annual Temp Range
Kauwerak	-5.9	-17.6	8.6	289.8	26.2
Mummy Caves	3.6	-2.1	10.3	1023.1	12.4
St. Michael	-2.7	-15.9	13.1	316.0	15.8
Umnak Island	4.5	-0.3	10.5	1455.7	10.8
Prince Rupert Harbour	7.1	1.3	11.1	2593.6	9.8
Steuben	11.1	-4.7	24.3	962.7	29.0
Fort Prince of Wales	-6.9	-26.7	12.0	431.6	38.7
Souris Valley	2.5	-16.0	16.3	516.2	32.3
Bussinger	9.5	-4.8	22.8	801.6	27.6
Huron Village	9.4	-4.8	22.6	897.9	27.4
Juntunen	6.3	-7.5	19.7	673.9	13.4
Edwards Mound	16.9	4.7	27.8	1377.7	23.1
Lake George	18.1	7.2	27.8	1517.4	20.6
Bell-Philhower	9.1	-4.2	21.8	1220.0	26.0
Hawikku	10.6	0.0	22.1	324.6	22.1
Kwastiyukwa	7.8	-3.4	19.6	330.2	23.0
Pueblo Bonito	9.9	-2.2	22.6	241.8	24.8
Native Point	-11.6	-30.0	9.3	285.7	39.3
Madisonville	12.6	-0.7	24.7	1070.6	25.4
Turpin	12.6	-0.7	24.7	1070.6	25.4
Sully	8.2	-7.9	23.7	379.5	31.6
Dr. Jarman	13.9	1.7	25.2	1380.0	23.5
Thompson Village	13.9	1.0	25.4	1363.5	24.4
Toqua	14.1	2.5	24.9	1483.1	22.4
Berrians Island	11.6	0.6	22.9	191.8	22.3

Chapter 5: Correlations and Linear Regressions

The relationship between surface area and body size in a living individual will be reflected in the morphology of the skeleton, as it is the frame upon which thermolytic and thermogenic soft tissues are situated Theoretically, the long, thin extremities and torso that are typical features of warm-adapted populations would be reflected in long limb bones, small epiphyseal breadths in the long bones, and short clavicles. In cold-adapted populations with short, robust limbs and wide or deep torsos, the expectation would be for short long bones with broad epiphyses and longer clavicles.

Materials and Methods

Multiple statistical tests were run on the data to detect if ecogeographic patterns are present within these samples. All statistical tests were performed using NCSS statistical software. All measurements are from left elements unless the left was poorly preserved or missing, in which case measurements from the corresponding right element were used.

Pearson correlations were calculated for each measurement and each climate variable. Raw measurements for males and females were analyzed separately. The results for females are given in table 5.1 and the males in table 5.2. Within each sex, each measurement was standardized to a mean of zero and standard deviation of one to produce a z-score, which allowed males and females to be pooled and analyzed together. The correlations for the pooled sample can be found in table 5.3. Scatterplots of the pooled measurements versus mean annual temperature can be found in the appendix.

Table 5.1. Pearson correlations, climate variables and individual raw data, females.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	.246	.129	.317	.208	.108	-.137
max diam midshaft	-.100	-.079	-.136	.101	-.005	.114
min diam midshaft	-.141	-.195	-.080	.217	.154	.254
max vertical head diam	-.171	-.245	-.100	.214	.219	.330
epicondylar br	-.078	-.106	-.084	.221	.065	.237
Radius						
max length	.486	.327	.561	.203	.101	-.382
ML diam midshaft	-.209	-.222	-.195	.229	.113	.314
AP diam midshaft	.157	.057	.235	.087	.127	-.097
max head br	-.026	-.122	.057	.137	.230	.179
Clavicle						
max length	.304	.242	.293	.204	-.036	-.187
SI diam midshaft	.026	-.034	.067	.206	.105	.075
AP diam midshaft	.092	.055	.089	.223	.000	.005
Femur						
max length	.158	.003	.307	.141	.255	-.069
bicondylar length	.150	.004	.289	.157	.234	-.054
AP diam midshaft	-.212	-.227	-.110	.090	.242	.282
ML diam midshaft	-.230	-.274	-.179	.182	.199	.333
circumf midshaft	-.269	-.341	-.168	.152	.290	.380
max head br	-.182	-.302	-.043	.200	.307	.353
AP subtroch diam	-.310	-.374	-.194	.088	.236	.434
ML subtroch diam	.122	.006	.195	.239	.204	-.001
epicondylar br	-.244	-.321	-.140	.112	.267	.373
Tibia						
max length	.314	.137	.471	.067	.235	-.249
max epiphyseal br proximal	-.233	-.376	-.062	.003	.362	.376
max epiphyseal br distal	-.328	-.409	-.205	.159	.325	.473
max diam nutrient foramen	.004	-.080	.088	.081	.207	.075
ML diam nutrient foramen	-.080	-.198	.041	.237	.289	.192
circumf nutrient foramen	-.022	-.146	.106	.154	.291	.139
Os Coxa						
max length	-.183	-.243	-.107	.106	.191	.313
iliac breadth	-.235	-.312	-.144	.123	.254	.374

Table 5.2. Pearson correlations, climate variables and individual raw data, males.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	.239	.124	.289	.069	.065	-.181
max diam midshaft	-.281	-.127	-.461	.334	-.244	.418
min diam midshaft	-.336	-.234	-.406	.243	-.080	.467
max vertical head diam	-.141	-.143	-.180	.258	.005	.299
epicondylar br	-.145	-.090	-.246	.259	-.113	.251
Radius						
max length	.500	.354	.493	.129	.021	-.412
ML diam midshaft	-.264	-.177	-.378	.293	-.110	.401
AP diam midshaft	-.033	-.011	-.142	.390	-.091	.182
max head br	-.106	-.108	-.176	.289	-.029	.295
Clavicle						
max length	.215	.168	.209	.060	-.030	-.101
SI diam midshaft	.083	.042	.077	.235	.019	.038
AP diam midshaft	.009	.035	-.054	.239	-.051	.035
Femur						
max length	.158	-.026	.338	-.093	.304	-.205
bicondylar length	.170	-.008	.342	-.087	.285	-.205
AP diam midshaft	-.116	-.129	-.065	.010	.079	.106
ML diam midshaft	-.272	-.233	-.282	.161	.039	.330
circumf midshaft	-.243	-.225	-.209	.059	.073	.274
max head br	-.300	-.311	-.241	.100	.140	.388
AP subtroch diam	-.274	-.252	-.222	-.039	.031	.344
ML subtroch diam	.054	-.053	.086	.243	.210	.010
epicondylar br	-.214	-.215	-.199	.146	.061	.315
Tibia						
max length	.354	.137	.531	-.139	.272	-.396
max epiphyseal br proximal	-.039	-.123	.049	.039	.135	.179
max epiphyseal br distal	-.287	-.342	-.208	.150	.233	.381
max diam nutrient foramen	.115	.066	.112	.083	.024	-.071
ML diam nutrient foramen	-.197	-.227	-.139	.095	.139	.195
circumf nutrient foramen	.055	-.029	.107	.096	.128	-.011
Os Coxa						
max length	-.298	-.316	-.262	.003	.172	.350
iliac breadth	-.257	-.304	-.172	-.060	.230	.304

Table 5.3. Pearson correlations, climate variables and z-scores, sexes pooled.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	.243	.126	.302	.126	.084	-.159
max diam midshaft	-.193	-.102	-.312	.241	-.128	.270
min diam midshaft	-.240	-.213	-.255	.237	.021	.360
max vertical head diam	-.152	-.188	-.142	.242	.096	.310
epicondylar br	-.111	-.094	-.173	.251	-.039	.241
Radius						
max length	.495	.343	.524	.157	.052	-.398
ML diam midshaft	-.238	-.197	-.294	.269	-.013	.357
AP diam midshaft	.056	.022	.026	.275	.000	.050
max head br	-.062	-.113	-.059	.228	.092	.233
Clavicle						
max length	.278	.203	.249	.119	-.032	-.143
SI diam midshaft	.056	.006	.073	.221	.058	.056
AP diam midshaft	.048	.045	.012	.230	-.029	.021
Femur						
max length	.160	-.012	.326	.001	.283	-.143
bicondylar length	.164	-.001	.322	.010	.264	-.138
AP diam midshaft	-.161	-.198	-.085	.041	.147	.187
ML diam midshaft	-.249	-.249	-.233	.177	.105	.326
circumf midshaft	-.252	-.276	-.188	.101	.162	.318
max head br	-.242	-.305	-.150	.145	.211	.367
AP subtroch diam	-.287	-.307	-.204	.022	.120	.383
ML subtroch diam	.089	-.023	.137	.244	.208	.002
epicondylar br	-.220	-.255	-.167	.142	.146	.332
Tibia						
max length	.339	.140	.508	-.056	.255	-.330
max epiphyseal br proximal	-.119	-.223	.001	.024	.227	.260
max epiphyseal br distal	-.303	-.370	-.204	.154	.275	.418
max diam nutrient foramen	.065	-.001	.103	.087	.106	-.003
ML diam nutrient foramen	-.145	-.215	-.061	.156	.204	.194
circumf nutrient foramen	.022	-.081	.109	.126	.201	.057
Os Coxa						
max length	-.243	-.281	-.190	.048	.180	.330
iliac breadth	-.247	-.307	-.159	.021	.239	.335

Each skeletal measurement was regressed on each climatic variable using ordinary least squares regression. Raw measurements for each sex were analyzed, as were the z-scores for the pooled sample. T-tests for each regression were performed to investigate if the slopes of the regression lines were significantly different from a slope of zero. The p-values for these tests are listed in table 5.4 for females, 5.5 for males, and 5.6 for the combined sample.

Results

The series of Pearson correlations and linear regressions show several patterns between climate variables and measurements. Measurements will be divided into groups for discussion: lengths, epiphyseal and head measurements, diaphyseal measurements, and measurements of the os coxa.

With regards to bone length, the four limb bones behaved in a similar manner in both males and females. In females, the maximum lengths of the humerus, radius, femur, and tibia all were correlated more strongly with mean July temperature than with any of the other climate variables, with values of .317, .561, .307, and .471 respectively. A parallel pattern is seen in the male subsample, with values of .289, .493, .338, and .531 respectively. Among males, radius maximum length was correlated slightly more strongly with mean annual temperature than mean July temperature (.500 versus .493). This does not negate the overall similarity in pattern though, as both correlations demonstrate a relationship between an increase in temperature and an increase in radius length. In the combined sample, the values for the correlations between mean July

Table 5.4. P-values, significance test for slope of regression lines, females.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	<.001	.024	<.001	<.001	.058	.016
max diam midshaft	.076	.158	.015	.049	.950	.041
min diam midshaft	.011	<.001	.156	<.001	.005	<.001
max vertical head diam	.003	<.001	.083	<.001	<.001	<.001
epicondylar br	.229	.089	.193	<.001	.282	<.001
Radius						
max length	<.001	<.001	<.001	.001	.099	<.001
ML diam midshaft	<.001	<.001	.001	<.001	.058	<.001
AP diam midshaft	.012	.367	<.001	.166	.042	.122
max head br	.769	.078	.338	.025	.001	.009
Clavicle						
max length	<.001	.001	<.001	.003	.624	.007
SI diam midshaft	.706	.609	.316	.002	.114	.265
AP diam midshaft	.174	.415	.190	.001	.996	.935
Femur						
max length	.006	.944	<.001	.013	<.001	.233
bicondylar length	.010	.928	<.001	.006	<.001	.352
AP diam midshaft	<.001	<.001	.047	.102	<.001	<.001
ML diam midshaft	<.001	<.001	.001	.001	<.001	<.001
circumf midshaft	<.001	<.001	.004	.006	<.001	.145
max head br	.002	<.001	.464	.001	<.001	<.001
AP subtroch diam	<.001	<.001	<.001	.060	<.001	<.001
ML subtroch diam	.018	.906	<.001	<.001	<.001	.980
epicondylar br	.001	<.001	.055	.072	<.001	<.001
Tibia						
max length	<.001	.022	<.001	.255	<.001	<.001
max epiphyseal br proximal	.003	<.001	.438	.971	<.001	<.001
max epiphyseal br distal	<.001	<.001	.003	.017	<.001	<.001
max diam nutrient foramen	.906	.144	.093	.103	<.001	.175
ML diam nutrient foramen	.136	<.001	.440	.058	<.001	<.001
circumf nutrient foramen	.717	.008	.049	.004	<.001	.012
Os Coxa						
max length	.011	.001	.138	.140	.007	<.001
iliac breadth	.003	<.001	.070	.120	.001	<.001

Table 5.5. P-values, significance test for slope of regression lines, males.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	<.001	.022	<.001	.005	.239	.001
max diam midshaft	<.001	.017	<.001	<.001	<.001	<.001
min diam midshaft	<.001	<.001	<.001	<.001	.125	<.001
max vertical head diam	.010	.008	.001	<.001	.940	<.001
epicondylar br	.013	.133	<.001	<.001	.041	<.001
Radius						
max length	<.001	<.001	<.001	.025	.747	<.001
ML diam midshaft	<.001	.002	<.001	<.001	.046	.161
AP diam midshaft	.614	.905	.015	<.001	.105	.002
max head br	.112	.104	.031	<.001	.667	<.001
Clavicle						
max length	.001	.011	.002	.373	.630	.130
SI diam midshaft	.197	.509	.233	.055	.780	.537
AP diam midshaft	.908	.587	.365	<.001	.412	.563
Femur						
max length	.003	.629	<.001	.084	<.001	<.001
bicondylar length	.001	.899	<.001	.113	<.001	<.001
AP diam midshaft	.214	.011	.189	.837	.136	.036
ML diam midshaft	<.001	<.001	<.001	.001	.476	<.001
circumf midshaft	<.001	<.001	<.001	.198	.173	<.001
max head br	<.001	.094	<.001	.046	.011	<.001
AP subtroch diam	<.001	<.001	<.001	.530	.568	<.001
ML subtroch diam	.256	.318	<.001	<.001	<.001	.889
epicondylar br	.001	.001	.008	.014	.349	<.001
Tibia						
max length	<.001	.013	<.001	.013	<.001	<.001
max epiphyseal br proximal	.598	.100	.514	.604	.071	.016
max epiphyseal br distal	<.001	<.001	.002	.023	<.001	<.001
max diam nutrient foramen	.020	.173	.024	.082	.674	.143
ML diam nutrient foramen	<.001	<.001	.006	.053	.007	<.001
circumf nutrient foramen	.258	.629	.035	.047	.016	.765
Os Coxa						
max length	<.001	<.001	<.001	.974	.014	<.001
iliac breadth	<.001	<.001	.020	.445	.002	<.001

Table 5.6. P-values, significance test for slope of regression lines, sexes pooled.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	<.001	.001	<.001	.001	.032	<.001
max diam midshaft	<.001	.007	<.001	<.001	.001	<.001
min diam midshaft	<.001	<.001	<.001	<.001	.580	<.001
max vertical head diam	<.001	<.001	<.001	<.001	.014	<.001
epicondylar br	.007	.023	<.001	<.001	.346	<.001
Radius						
max length	<.001	<.001	<.001	<.001	.213	<.001
ML diam midshaft	<.001	<.001	<.001	<.001	.754	<.001
AP diam midshaft	.183	.601	.547	<.001	.999	.238
max head br	.195	.017	.218	<.001	.052	<.001
Clavicle						
max length	<.001	<.001	<.001	.013	.510	.003
SI diam midshaft	.225	<.001	.114	<.001	.208	.226
AP diam midshaft	.294	.332	.800	<.001	.529	.650
Femur						
max length	<.001	.763	<.001	.982	<.001	<.001
bicondylar length	<.001	.985	<.001	.797	<.001	.001
AP diam midshaft	<.001	<.001	.025	.275	<.001	<.001
ML diam midshaft	<.001	<.001	<.001	<.001	.006	<.001
circumf midshaft	<.001	<.001	<.001	.009	<.001	<.001
max head br	<.001	<.001	<.001	<.001	<.001	<.001
AP subtroch diam	<.001	<.001	<.001	.534	.001	<.001
ML subtroch diam	.014	.518	<.001	<.001	<.001	.954
epicondylar br	<.001	<.001	<.001	.002	.002	<.001
Tibia						
max length	<.001	.001	<.001	.176	<.001	<.001
max epiphyseal br proximal	.028	<.001	.979	.657	<.001	<.001
max epiphyseal br distal	<.001	<.001	<.001	.001	<.001	<.001
max diam nutrient foramen	.082	.982	.006	.020	.005	.931
ML diam nutrient foramen	<.001	<.001	.100	<.001	<.001	<.001
circumf nutrient foramen	.564	.032	.004	.001	<.001	.131
Os Coxa						
max length	<.001	<.001	<.001	.341	<.001	<.001
iliac breadth	<.001	<.001	.003	.693	<.001	<.001

temperature and maximum limb bone lengths were intermediate between the values calculated for the sexes separately. The somewhat stronger correlations seen in the radius and tibia suggest that they elongate at a more rapid pace in relationship to increased temperature than the bones of the proximal limb segments do. This possibility will be tested in the next chapter.

Limb bone length was not as strongly correlated with mean annual or mean January temperature. Maximum femur length shows the lowest correlation with mean January temperature at .003 in females and -.026 in males. Among the limb bone lengths, only the length of the femur does not produce a slope significantly different from zero when it is regressed on mean January temperature. The pattern is present in both sexes, though is more pronounced in females ($p = .944$ compared with $p = .629$).

Maximum length of the clavicle was moderately correlated with mean annual temperature, mean January temperature, and mean July temperature in both sexes. Mean annual temperature showed the highest correlation in both sexes, .304 in females and .215 in males, than with mean July temperature, .293 in females and .209 in males.

Males and females also exhibit parallel patterns in epiphyseal dimensions. In the female subsample, humerus vertical head diameter, epicondylar breadth of the humerus, femur maximum head diameter, femur epicondylar breadth, and the proximal and distal epiphyseal breadths of the tibia were most strongly correlated with latitude (.330, .237, .353, .315, .376, and .473 respectively), all showing an increase in size with an increase in latitude. Radius head breadth was most highly correlated with annual temperature range, though the relationship is not especially strong (.230).

Among the males, humerus vertical head diameter, radius head breadth, femur maximum head diameter, femur epicondylar breadth, and the proximal and distal epiphyseal breadths of the tibia are most strongly correlated with latitude (.299, .295, .388, .315, .179, and .381 respectively). Humerus epicondylar breadth is most highly correlated with mean annual precipitation (.259), though it has similar correlations with mean July temperature (.246) and latitude (.251). In the combined sample, radius head breadth and humerus epicondylar breadth follow the patterns seen in male subsample.

In both sexes, all measures of epiphyseal size produce slopes significantly different from zero when regressed on latitude. In the females subsample, linear regression produced significant results for all epiphyseal measurements and mean January temperature, with the exception of epicondylar breadth ($p = .089$). Among males, regression with mean January temperature only produced significant results for humerus vertical head diameter, femur epicondylar breadth, and tibia distal epiphyseal breadth. All other climate variables produced inconsistent results for epiphyseal measurements.

Unlike limb bone length and epiphyseal measurements, measures of diaphyseal size do not show a clear association with any one climate variable. The male and female subsamples show somewhat different patterns, though there is some overlap between the sexes. Among females, the majority of the diaphyseal measurements are most strongly and positively correlated with latitude. Humerus maximum diameter at midshaft and radius anterior-posterior diameter at midshaft are most strongly correlated with mean January temperature (-.136 and .235 respectively). Both the superior-inferior and anterior-posterior midshaft measurements of the clavicle and medial-lateral

subtrochanteric diameter of the femur are most strongly correlated with mean annual precipitation (.206, .233, and .239 respectively).

As is seen in the female subsample, most of the diaphyseal measurements in the male subsample are most strongly correlated with latitude. Humerus maximum diameter at midshaft is strongly correlated with mean July temperature (-.461), though it shows the second highest correlation with latitude among all of the measurements (.418). Radius anterior-posterior diameter at midshaft, superior-inferior and anterior-posterior midshaft diameters of the clavicle, and medial-lateral subtrochanteric diameter of the femur are most strongly correlated with mean annual precipitation (.390, .235, .239, and .243 respectively). Anterior-posterior midshaft diameter of the femur is most highly correlated with mean January temperature (-.129), although it is not strongly correlated with any climate variable.

Regression analysis showed no clear patterns for diaphyseal measurements. Many of them produce significant results with multiple climate variables. In females, both diaphyseal clavicle measurements only produce significant results when regressed on mean annual precipitation ($p = .002$ and $p = .001$) and maximum diameter at the nutrient foramen is only significant for annual temperature range ($p = <.001$). Similar patterns are seen in the male subsample, with the exception of no significant results for clavicle superior-inferior midshaft diameter (though borderline insignificant with mean annual precipitation at $p = .055$) and maximum diameter at the nutrient foramen producing significant results with mean annual temperature ($p = .020$) and mean July temperature ($p = .024$)

In both sexes, maximum length of the os coxa was most strongly correlated with latitude, at .313 for females and .350 for males. Iliac breadth was also most strongly correlated with latitude at .374 for females and .304 for males. In females, regression analysis yielded statistically significant results for all variables except mean July temperature and mean annual precipitation. The male subsample was statistically significant for all variables except mean annual precipitation. The total sample followed the same trend as males, with all climate variables except mean annual precipitation producing statistically significant results.

Discussion

The high correlation of limb bone length and mean July temperature show that as temperature increases, limb bone length increases, as would be expected if Allen's rule were valid for these samples. Heat stress appears to be the driving factor, as the correlations with mean July temperature are stronger than those with mean annual temperature or mean January temperature. This is especially true for the femur, whose length is barely correlated with mean January temperature in either sex.

Maximum length of the clavicle does not seem to follow ecogeographic expectations. It increases in size as temperature increases, suggesting that the upper torso and shoulder girdle become wider as temperature increases. While this is not the pattern expected if the body were to decrease in width in response to increased temperature, this pattern is also seen in the Boas anthropometric data (Jantz et al. 2007).

The strong relationships between latitude and epiphyseal measures and their relatively weak and inconsistent relationships with the other climate variables suggest

that the latitude variable encompasses more than temperature and precipitation data. Other selective or nonselective forces may be affecting these measurements, such as topographic variation or differences in food resources. The inconsistent correlations in radius head breadth and humerus epicondylar breadth between the sexes suggests that climate variables are not greatly or consistently influencing these measurements. As the elbow joint show significant sexual size dimorphism, it perhaps provides little useful information about climate adaptation, as potential adaptations may be masked by a stronger dimorphic component. Epiphyseal size, especially femoral head diameter, may also be related to gross differences in body size (Auerbach and Ruff 2004).

The inconsistent patterns seen in the diaphyseal measurements suggest that they are being influenced by variables other than climate. Antemortem biomechanical stresses have caused cortical remodeling in some of the dimensions measured. The complex nature of the latitude variable is a complicating factor in the analysis of these measures as it was in measures of epiphyseal size. Diaphyseal size may be more influenced by the function of the long bone as a structural support for the body than it is influenced by ecogeographical factors.

The analysis of the os coxa produced very similar results in both sexes, suggesting that the dimorphic features of this element do not greatly impact its relationship with climate. The general trend of longer os coxa and broader ilia with increasing latitude may be correlated to a worldwide trend toward increase in bi-iliac breadth with increase in latitude (Ruff 1991), a trend that would be expected if ecogeography was a significant influence on the morphology of this element.

Chapter 6: Analysis of Size and Shape Variables

As noted in the previous chapter, the humerus, radius, femur, and tibia exhibited moderately strong correlations with mean July temperature. In both sexes, the tibia and the radius were more highly correlated with this variable than either the femur or the humerus. The correlations and linear regressions discussed in chapter five suggest that the bones of the distal limb segments increase in length more rapidly with increased temperature than the bones of the proximal limb segments. To explore this question further, the relationships of all of the limb bones and the climate variables will be analyzed using "size" and "shape" variables (Darroch and Mosimann 1985).

Materials and Methods

Size and shape variables were created using the natural logarithms of humerus maximum length, radius maximum length, femur maximum length, and tibia maximum length (Darroch and Mosimann 1985, Meadows Jantz and Jantz 1999). As the creation of the size variables requires the presence of maximum length measurements for all four limb bones used in this analysis, only individuals with all four of these elements were used. This reduced the sample sizes in both sexes by a considerable degree (see table 6.1 for sample sizes by site). Due to the similarity of the relationships between limb bone lengths and climate variables demonstrated in chapter 5, males and females were analyzed separately and no attempt was made to pool the sexes for this portion of the analysis.

Table 6.1. Sample sizes for Mosimann variables.

Sites	Males	Females	Total
Kauwerak	6	3	9
Mummy Caves	11	9	20
St. Michael	7	5	12
Umnak Island	8	2	10
Prince Rupert Harbour	14	5	19
Steuben	6	2	8
Fort Prince of Wales	1	0	1
Souris Valley	8	3	11
Huron Village	2	1	3
Juntunen	8	4	12
Edwards Mound	2	1	3
Lake George	2	0	2
Bell-Philhower	3	6	9
Hawikku	30	44	74
Kwastiyukwa	3	5	8
Pueblo Bonito	3	9	12
Native Point	24	23	47
Madisonville	20	23	43
Turpin	4	3	7
Sully	24	12	36
Dr. Jarman	6	8	14
Thompson Village	1	3	4
Toqua	10	5	15
Berrians Island	6	3	9
Totals	209	179	388

This type of analysis allows for the analysis of changes in shape relative to overall size. Mosimann-type variables, as are used here, are superior in to various residual analyses for identifying specimens of the shape but different sizes (Jungers et al. 1995). The first variable created is the "size" variable, the arithmetic mean of the logarithms of the measurements to be examined. This variable functions as a measure of isometric size from the four limb bones (Jungers et al. 1995). Each size variable is unique to the individual, so only individuals with all four of the limb bone measurements were included in this portion of the analysis. The "shape" variables were created for each measurement by subtracting the log transformed size variable from the log of each measurement (Darroch and Mosimann 1985, Meadows Jantz and Jantz 1999).

Each log transformed measurement was regressed on the size variable to determine if the lengths of the long bones were isometric with overall size. A slope of one indicates an isometric relationship exists between the measurement and size, meaning that as an individual increases in size, the measurement increases at a similar rate. A slope less than one indicates that the measurement is negatively allometric and therefore increases at a slower rate than size does. A slope greater than one demonstrates positive allometry, in which the measurement increases at a greater rate than size does (Holliday 1997a).

Each shape variable was regressed onto the five climate variables to determine if the bone lengths increase or decrease in relationship to these climate variables when isometric size is removed. Significant results indicate that changes in bone length unrelated to size correspond to changes in the climate variables.

Results

The slopes and standard errors from the measurement on size regressions can be found in table 6.2. The bones of the distal limb segments are positively allometric with size. Radius length was the most positively allometric measurement in the female subsample, while the tibia length was the most positively allometric measurement among males. The bones of the proximal segments are negatively allometric in size. Femur length was the most negatively allometric measurement among females, while the humerus length was the most negatively allometric measurement among males.

To test if the slopes of the measurement on size regressions were significantly different from a slope of one, the difference between each slope and a slope of one was calculated. If this difference was larger than two standard errors, then the slope of the regression line is significantly different from one at the $\alpha = .05$ level. In table 6.2, slopes that are significantly different from one are in bold font.

The slopes for the size on climate variables and shape on climate variables regressions are tabulated in tables 6.3 for females and 6.4 for males. Size was significant for all climate variables except annual temperature range in the female subsample. Among males, size was significant only for mean annual temperature, mean January temperature, and mean July temperature. In both sexes the radius and femur produced significant results for all five climate variables. Radius shape increased in all cases. Femur shape decreased with increases in mean annual temperature, mean January temperature, and mean July temperature and increased with increases in mean annual precipitation and annual temperature range. In both sexes humerus shape decreased with increases in mean annual temperature and mean July temperature. Humerus shape also

Table 6.2. Slopes and standard errors, regressions of log transformed bone length on size. Slopes in bold are significantly different from a slope of 1 at the α = .05 level.

Sex	Hum Shape	Rad Shape	Fem Shape	Tib Shape
Females				
slope	**.895**	**1.188**	**.873**	1.045
SE	.032	.038	.031	.030
Males				
slope	**.857**	**1.119**	**.889**	**1.135**
SE	.028	.037	.029	.027

Table 6.3. Pearson correlations for size and shape variables regressed on climate variables, females.

Climate variables	Size	Hum Shape	Rad Shape	Fem Shape	Tib Shape
Mean Annual Temp	.379	-.282	.679	-.573	.009
Mean Jan Temp	.262	-.175	.655	-.580	-.070
Mean July Temp	.457	-.400	.583	-.457	.142
Mean Annual Precip	.215	.044	.277	-.179	-.228
Annual Temp Range	-.022	-.080	-.369	.391	.165

Table 6.4. Slopes and p-values for size and shape variables regressed on climate variables, males.

Climate variables	Size	Hum Shape	Rad Shape	Fem Shape	Tib Shape
Mean Annual Temp	.371	-.265	.598	-.576	.090
Mean Jan Temp	.202	-.109	.605	-.577	-.082
Mean July Temp	.485	-.419	.383	-.403	.354
Mean Annual Precip	-.014	.184	.314	-.231	-.366
Annual Temp Range	.066	-.244	-.422	.407	.373

decreased with increased annual temperature range in males. Tibia shape was not strongly related to many climate variables. Among females, tibia shape was only significant with mean annual precipitation and annual temperature range at the $\alpha = .05$ level. The pattern was similar among males, with mean July temperature also being significant.

Discussion

The allometric relationships among the size variable and the four bone lengths supports the hypothesis that the distal limb segments increase more rapidly with an increase in temperature than the proximal segments do. This pattern is in concordance with the ecogeographical expectations. The distal limb segments are thinner than the proximal ones and therefore have a higher surface area to volume ratio than the proximal segments (Holliday 1999). An increase in the length of the distal segments with greater temperature causes an increase in the surface area to volume ratio, which would be beneficial in climates where efficient heat loss would be advantageous.

Distal abbreviation in the limbs supports the idea that the indigenous populations of North America have resided on the continent long enough to have undergone considerable adaptation to climate. If distal abbreviation occurs late in the process of adaptation to cold stress (Holliday 1999), then evidence of it suggests that earlier processes such as the overall shortening of the extremities had previously occurred.

The positive slopes of all of the significant size versus climate variable regressions support the hypothesis of climate related patterns in morphology. As the size variable is reflective of an increase in overall limb bone length, an increase in size which

corresponds to an increase in temperature indicates that the limbs become longer with increased temperature. While all measures of temperature show this relationship, annual temperature range and mean annual precipitation have not significantly associated with overall limb bone length.

The negative slopes for humerus and femur shape and temperature variables do not indicate that humerus length and femur length decrease as temperature increases. Rather what these regressions demonstrate is that as temperature increases, humerus length and femur length contribute less to the size variable. This is the pattern that would be expected if the radius and tibia are contributing more to the size variable as temperature increases, as would be expected if elongation of the distal limb segments were occurring with increased temperature (or, similarly, if distal foreshortening were occurring with decreased temperatures). This is precisely the pattern of allometric relationships among these measurements documented in the series of measurement on size regressions.

Chapter 7: Multivariate Analyses

Two separate multivariate analyses were performed to determine if there were complex relationships among the climate variables and osteometric measurements not detected in the univariate statistics. First, a series of multiple regressions were performed in which all climate variables were regressed onto each measurement. In the second analysis canonical correlation was used to determine the relationships between six of the measurements and five of the climate variables.

Multiple Regressions

Multiple regression analysis was used in order to examine the relationships among the climate variables and each measurement. Mean annual temperature, mean January temperature, mean July temperature, mean annual precipitation, and annual temperature range were regressed onto each measurement. The sexes were analyzed separately. The models for each measurement and the p-values and adjusted r^2 for the models can be found in tables 7.1 and 7.2. Climate variables that were not found to significantly influence the slope of the regression when all other climate variables were excluded are italicized.

Results – Multiple Regressions

Several interesting relationships between the measurements and the climate variables emerge from the multivariate regressions. All of the measurements produced regressions that were significant at the $\alpha = .05$ level. Only two, maximum diameter of the

Table 7.1. Multivariate regression models, females. Variables in italics are not significant at α = .05.

Measurement	adj r^2	p (model)	Model
Humerus			
max length	.216	<.001	108.092 - .619*ATR[1] + 6.104*MAT[2] - 4.235*MJANT[3] - *1.302*MJULT* [4]+ 5.527 E-03*MAP[5]
max diam midshaft	.027	.016	42.267 - 5.187 E-03*ATR + .405*MAT - .215*MJANT - .265*MJULT + 1.515 E-04*MAP
min diam midshaft	.164	<.001	19.244 - 3.118 E-02*ATR + .139*MAT - .195*MJANT + 2.951 E-02*MJULT + *1.237 E-03*MAP*
max vertical head diam	.252	<.001	82.348 - *.082*ATR* + 1.713*MAT - 1.101*MJANT - .774*MJULT + 1.151 E-03*MAP
epicondylar br	.161	<.001	113.374 - *.089*ATR* + 2.362*MAT - 1.333*MJANT - 1.236*MJULT + *2.948 E-04*MAP*
Radius			
max length	.431	<.001	-94.523 - *.148*ATR* + 8.550*MAT - 4.737*MJANT - 2.763*MJULT + *2.521 E-03*MAP*
ML diam midshaft	.156	<.001	29.253 - *4.238 E-02*ATR + .176*MAT - .198*MJANT - 3.948 E-02*MJULT* + 1.033 E-03*MAP
AP diam midshaft	.125	<.001	7.849 - *3.538 E-02*ATR* + .594*MAT - .355*MJANT - .233*MJULT - *6.277 E-05*MAP*
max head br	.181	<.001	35.792 + *7.175 E-03*ATR* + 1.096*MAT - .601*MJANT - .554*MJULT + *1.156 E-04*MAP*
Clavicle			
max length	.144	<.001	90.843 - *.175*ATR + 4.553*MAT* - 2.455*MJANT - 1.935*MJULT + *1.407 E-03*MAP*
SI diam midshaft	.097	<.001	8.990 - *3.119 E-02*ATR + .348*MAT* - .242*MJANT - *.112*MJULT* + 6.632 E-04*MAP
AP diam midshaft	.088	<.001	8.908 - 5.646 E-02*ATR + *.357*MAT* - .252*MJANT - *.105*MJULT + 5.245 E-04*MAP*
Femur			
max length	.227	<.001	61.145 - 1.163*ATR + 6.240*MAT - 5.757*MJANT + *.557*MJULT* + 1.015 E-02*MAP
bicondylar length	.254	<.001	67.463 - 1.136*ATR + *4.778*MAT* - 4.911*MJANT + *1.141*MJULT* + 1.126 E-02*MAP
AP diam midshaft	.149	<.001	36.483 - *6.984 E-02*ATR + .175*MAT - .309*MJANT + 8.075 E-02*MJULT* + 1.325 E-03*MAP
ML diam midshaft	.209	<.001	61.017 - *.058*ATR* + .883*MAT - .620*MJANT - .401*MJULT + 1.080 E-03*MAP
circumf midshaft	.252	<.001	163.082 - *.161*ATR* + 1.932*MAT - 1.614*MJANT - *.657*MJULT* + 3.958 E-03*MAP
max head br	.334	<.001	61.718 - 9.638 E-02*ATR + 1.148*MAT - .915*MJANT - *.328*MJULT* + 1.965 E-03*MAP
AP subtroch diam	.246	<.001	45.776 - .154*ATR + *.337*MAT* - .506*MJANT + *7.307 E-02*MJULT* + 1.402 E-03*MAP
ML subtroch diam	.215	<.001	25.261 - *5.708 E-02*ATR* + 1.659*MAT - 1.022*MJANT - .637*MJULT + 1.139 E-03*MAP
epicondylar br	.179	<.001	131.888 - *4.375 E-02*ATR* + 1.765*MAT - 1.167*MJANT - .825*MJULT + *1.247 E-03*MAP*
Tibia			
max length	.363	<.001	-35.542 - .844*ATR + 10.987*MAT - 7.347*MJANT - *2.452*MJULT + 4.431 E-04*MAP*
max epiphyseal br proximal	.282	<.001	221.791 + *9.303 E-02*ATR* + 5.400*MAT - 2.856*MJANT - 3.082*MJULT - 2.631 E-03*MAP
max epiphyseal br distal	.297	<.001	140.316 - *2.514 E-02*ATR* + 2.519*MAT - 1.560*MJANT - 1.307*MJULT + *1.198 E-03*MAP*
max diam nutrient foramen	.075	<.001	28.648 + *5.518 E-03*ATR + .764*MAT* - .496*MJANT - *.272*MJULT + 7.354 E-04*MAP*
ML diam nutrient foramen	.272	<.001	20.363 - *.048*ATR* + .616*MAT - .532*MJANT - *.102*MJULT* + 1.796 E-03*MAP
circumf nutrient foramen	.208	<.001	64.778 - *.1077*ATR* + 2.386*MAT - 1.775*MJANT - *.600*MJULT* + 3.864 E-03*MAP
Os Coxa			
max length	.148	<.001	330.932 - *.241*ATR* + 4.682*MAT - 3.091*MJANT - 2.100*MJULT + *3.531 E-03*MAP*
iliac breadth	.284	<.001	305.931 - .548*ATR + 5.802*MAT - 3.962*MJANT - 2.426*MJULT + *2.469 E-03*MAP*

[1] annual temperature range
[2] mean annual temperature
[3] mean January temperature
[4] mean July temperature
[5] mean annual precipitation

Table 7.2. Multivariate regression models, males. Variables in italics are not significant at α = .05.

Measurement	adj r^2	p (model)	Model
Humerus			
max length	.223	<.001	118.130 - 1.467*ATR + 5.183*MAT - 4.374*MJANT - *.179*MJULT + 3.531E-03*MAP*
max diam midshaft	.298	<.001	78.972 - .101*ATR + .472 *MAT - .345*MJANT - .323*MJULT + 8.344 E-04*MAP
min diam midshaft	.235	<.001	42.554 - 5.499 E-02*ATR - *.269*MAT + 4.812 E-03*MJANT + .166*MJULT* + 1.378 E-03*MAP
max vertical head diam	.220	<.001	85.017 - .115*ATR + 1.240*MAT - .861*MJANT - .532*MJULT + .001*MAP
epicondylar br	.183	<.001	106.827 - .227*ATR + .936*MAT - .755*MJANT - *.350*MJULT* + 1.331 E-03*MAP
Radius			
max length	.439	<.001	-19.437 - .911*ATR + 9.167*MAT - 5.362*MJANT - 2.897*MJULT - *1.120 E-03*MAP*
ML diam midshaft	.236	<.001	45.109 - 6.384 E-02*ATR + *.205*MAT* - .209*MJANT - *.106*MJULT* + 9.638 E-04*MAP
AP diam midshaft	.252	<.001	17.369 - 5.292 E-02*ATR + .261*MAT - .225*MJANT - *6.159 E-02*MJULT* + 9.040 E-04*MAP
max head br	.217	<.001	40.774 - 5.086 E-02*ATR + .699*MAT - .436*MJANT - .331 *MJULT + 5.194 E-04*MAP
Clavicle			
max length	.045	.009	119.891 - *.083*ATR* + 3.385*MAT - *1.701*MJANT - 1.565*MJULT - 1.562 E-03*MAP*
SI diam midshaft	.103	<.001	3.031 - *4.186 E-02*ATR + .180*MAT - .179*MJANT + 1.634 E-02*MJULT* + 9.221 E-04*MAP
AP diam midshaft	.052	.003	8.135 - *1.315 E-02*ATR - .110*MAT + 1.792 E-02*MJANT + 9.933 E-02*MJULT* + 8.726 E-04*MAP
Femur			
max length	.207	<.001	115.696 - .750*ATR + *3.158*MAT* - 3.434*MJANT + *1.272*MJULT* + 6.298 E-03*MAP
bicondylar length	.198	<.001	106.205 - .743*ATR + *2.835*MAT* - 3.172*MJANT + *1.364*MJULT* + 6.008 E-03*MAP
AP diam midshaft	.032	.004	30.231 - 9.109 E-02*ATR - *.229*MAT - 5.145 E-02*MJANT + .268*MJULT* + 8.147 E-04*MAP
ML diam midshaft	.145	<.001	53.140 - *2.592 E-02*ATR + 9.724 E-02*MAT - .171*MJANT - .029*MJULT* + 1.145 E-03*MAP
circumf midshaft	.084	<.001	137.603 - *.166*ATR - .206*MAT - .305*MJANT + .313*MJULT* + 2.492 E-03*MAP
max head br	.195	<.001	80.258 - *6.500 E-02*ATR + .355*MAT* - .405*MJANT - *8.496 E-02*MJULT* + 1.444 E-03*MAP
AP subtroch diam	.116	<.001	44.972 - .165*ATR - *.215*MAT - .128*MJANT* + .270*MJULT + *5.320 E-04*MAP*
ML subtroch diam	.273	<.001	37.153 + *.014*ATR* + 1.418*MAT - .885*MJANT - .572*MJULT + 1.914 E-03*MAP
epicondylar br	.119	<.001	130.823 - *9.604 E-02*ATR + .7209*MAT* - .636*MJANT - *.279*MJULT* + 2.093 E-03*MAP
Tibia			
max length	.366	<.001	-120.028 - .968*ATR + 6.170*MAT - 4.606*MJANT + *4.315 E-02*MJULT - 7.183 E-04*MAP*
max epiphyseal br proximal	.045	.023	68.985 - *.117*ATR + .486*MAT - .514*MJANT + 3.128 E-02*MJULT + 1.561 E-03*MAP*
max epiphyseal br distal	.253	<.001	103.859 - *2.753 E-02*ATR* + 1.016*MAT - .777*MJANT - *.445*MJULT* + 2.204 E-03*MAP
max diam nutrient foramen	.040	.001	27.053 - *6.332 E-02*ATR* + .665*MAT - .418*MJANT - *.220*MJULT + 3.780 E-04*MAP*
ML diam nutrient foramen	.107	<.001	41.281 - *1.935 E-02*ATR + .110*MAT - .210*MJANT + 2.343 E-02*MJULT* + 1.317 E-03*MAP
circumf nutrient foramen	.084	<.001	68.317 - *.132*ATR* + 1.270*MAT - 1.026*MJANT - *.185*MJULT* + 2.869 E-03*MAP
Os Coxa			
max length	.169	<.001	417.048 - *.130*ATR* + 4.137*MAT - 2.506*MJANT - 2.364*MJULT + *1.886 E-04*MAP*
iliac breadth	.129	<.001	291.847 - *.169*ATR* + 3.176*MAT - 2.108*MJANT - 1.567*MJULT + *7.993 E-04*MAP*

humerus at midshaft in females and maximum proximal epiphyseal breadth of the tibia in males, produced regressions that were not significant at the $\alpha = .01$ level.

The four long bone lengths are show comparable patterns in both sexes. The models for these measurements produced r^2 greater than .200, with the tibia producing r^2 of .363 in females and .366 in males. Radius length showed an even stronger relationship, with r^2 of .431 in females and .439 in males. Among the long bone lengths, mean January temperature had significant partial regression coefficients in all eight of the regressions, while annual temperature range and mean annual temperature were significant in seven of the eight models.

Results for the epiphyseal dimensions were not consistent between the sexes. The largest discrepancies are for femoral head breadth ($r^2 = .334$ in females, .195 in males) and maximum proximal epiphyseal breadth of the tibia ($r^2 = .282$ in females, .045 in males). All other r^2 values differed by less than .05 between the sexes. With the exception of maximum proximal epiphyseal breadth of the tibia in males, all r^2 values for epiphyseal measurements fell between .119 and .334. Mean January temperature had significant partial regression coefficients for all measures of epiphyseal breadth. Mean annual temperature and mean annual precipitation were significant in six of eight cases.

Models and r^2 for the diaphyseal measurements were not similar between the sexes. The was very little consistency in which climate variables were associated with these measurements, with the exception of mean annual precipitation, which was significant in 12 of 14 measurements among males and 10 of 14 among females.

In both sexes the measurements of the os coxa were significantly associated with mean annual temperature, mean January temperature, and mean July temperature. The r^2

values for these measurements varied in size, from .129 for iliac breadth in males to .284 for iliac breadth in females.

Discussion – Multiple Regressions

The climate variables used in this multiple regression analysis can only partially explain the variation observed in these measurements. The highest r^2 values in both sexes are associated with radius length, suggesting that approximately 43% of the variation in this measurement can be attributed to variation in the climate variables. Tibia length shows a similar though less robust pattern, with approximately 36% of the variation in this measurement being attributable to variation in the climate variables. Humerus and femur length have more modest r^2 values, suggesting that these measurements are less strongly associated with these climate variables.

Many of the epiphyseal measurements have r^2 greater than .200, which supports the hypothesis that there is some variation in these measurements attributable to climate variation, though the explanatory powers of these variables is rather modest. There is great variation in the r^2 values of the diaphyseal measurements, suggesting that there is not a clear, straightforward relationship among the diaphyseal dimensions in general and any combination of these climate variables. The measurements of the os coxa show a clear relationship with the temperature variables, although the r^2 values for these measurements are not particularly large.

Canonical Correlation

Canonical correlation was performed to examine multivariate relationships among several measurements and the five climate variables. Humerus length, radius length, femur length, tibia length, humerus head diameter, and femur head diameter were used in this procedure as these measurements were available for many of the individuals in the sample. These six measurements are also representative of or correlated with anthropometric dimensions that are of interest in this study, specifically limb length and body mass. Additionally, they were highly correlated with multiple climate variables, as was demonstrated by univariate correlations, linear regressions, and multiple regressions. Each sex was analyzed separately.

Results – Canonical Correlation

Canonical correlation produced four canonical variates that were significant at the $\alpha = .05$ level in the female subsample. Canonical correlations, r^2, F-values, p-values, and Wilk's Lambas for the female subsample is provided in table 7.3.

Table 7.4 contains the standardized canonical coefficients and structure correlation coefficients generated from the osteometric data for females. Canonical variate 1 is most heavily weighted by the lengths of the radius and tibia and the humeral and femoral head breadths. Canonical variate 2 is heavily weighted by all of the measurements. Canonical variate 3 is most heavily weighted by the lengths of the femur and tibia and humeral head breadth. Canonical variate 4 is heavily weighted by humerus and tibia length.

Table 7.3. Canonical correlations, females.

Variate	Canon. Corr	r^2	F-value	p	Wilk's Lambda
1	.771	.594	10.55	<.001	.190
2	.624	.389	6.61	<.001	.467
3	.407	.166	3.66	<.001	.764
4	.225	.051	2.33	.032	.916

Table 7.4. Metric canonical coefficients and structure correlation coefficients, females.

Measurement	Metric CV1	Metric CV2	Metric CV3	Metric CV4
Humerus Length				
CC	.329	.623	-.440	1.287
SCC	-.173	-.576	-.042	.299
Humerus Head				
CC	.181	-.443	-.645	.334
SCC	.410	-.737	-.445	.159
Radius Length				
CC	-1.352	-.626	-.816	-1.204
SCC	-.602	-.714	.012	.129
Femur Length				
CC	.037	-.241	.506	-2.118
SCC	-.029	-.744	.361	-.022
Femur Head				
CC	.533	-.332	.195	.018
SCC	.515	-.755	-.089	-.097
Tibia Length				
CC	.307	-.225	1.141	2.078
SCC	-.341	-.690	.473	.324

Table 7.5 contains the standardized canonical coefficients and structure correlation coefficients generated from the climate data for the female subsample. Canonical variate 1 is most heavily weighted by mean annual, mean January, and mean July temperature. Canonical variate 2 is most heavily weighted by mean July temperature, mean annual precipitation, and annual temperature range. Canonical variate 3 is most heavily weighted by mean annual precipitation and annual temperature range. Canonical variate 4 is most heavily weighted by annual temperature range.

In the male subsample canonical correlation produced three canonical variates that were significant at the $\alpha = .05$ level. A fourth variate of borderline significance ($p = .052$) was included in the analysis. Canonical correlations, r^2, F-values, p-values, and Wilk's Lambas for the female subsample is provided in table 7.6.

Table 7.7 contains the standardized canonical coefficients and structure correlation coefficients generated from the osteometric data for males. Canonical variate 1 is most heavily weighted by the lengths of the humerus, radius, and tibia and femoral head breadth. Canonical variate 2 is most heavily weighted by humeral head breadth, femur length, and tibia length. Canonical variate 3 is heavily weighted by all measurements. Canonical variate 4 is most heavily weighted by humerus length.

Table 7.8 contains the standardized canonical coefficients and structure correlation coefficients generated from the climate data for the male subsample. Canonical variate 1 is most heavily weighted by mean annual, mean January, and mean July temperature. Canonical variate 2 is most heavily weighted by mean July temperature, mean annual precipitation, and annual temperature range. Canonical variate

Table 7.5. Climate canonical coefficients and structure correlation coefficients, females.

Measurement	Climate CV1	Climate CV2	Climate CV3	Climate CV4
Mean annual temp				
CC	-1.398	-4.469	-5.729	14.746
SCC	-.931	-.264	-.086	.067
Mean Jan temp				
CC	-.927	4.327	2.237	-12.649
SCC	-.908	-.055	-.274	.060
Mean July temp				
CC	.960	.479	3.743	-4.194
SCC	-.826	-.438	.332	.025
Mean annual precip				
CC	.399	-.662	-.199	-.998
SCC	-.069	-.522	-.757	-.144
Annual temp range				
CC	-.672	.247	-.467	-2.696
SCC	.479	-.311	.582	-.272

Table 7.6. Canonical correlations, males.

Variate	Canon. Corr	r^2	F-value	p	Wilk's Lambda
1	.813	.661	13.44	<.001	.146
2	.625	.391	7.83	<.001	.432
3	.485	.235	5.04	<.001	.710
4	.268	.072	2.11	.052	.928

Table 7.7. Metric canonical coefficients and structure correlation coefficients, males.

Measurement	Metric CV1	Metric CV2	Metric CV3	Metric CV4
Humerus Length				
CC	.077	.216	-.725	-1.859
SCC	-.365	-.144	.508	-.633
Humerus Head				
CC	-.086	.558	.739	.430
SCC	.124	.521	.776	-.241
Radius Length				
CC	-1.191	.877	.180	.724
SCC	-.765	-.139	.522	-.245
Femur Length				
CC	.403	-.126	.797	1.555
SCC	-.180	-.456	.705	-.210
Femur Head				
CC	.507	-.024	.029	-.582
SCC	.401	.153	.713	-.349
Tibia Length				
CC	.007	-1.454	.191	-.730
SCC	-.459	-.556	.615	-.311

Table 7.8. Climate canonical coefficients and structure correlation coefficients, males.

Measurement	Climate CV1	Climate CV2	Climate CV3	Climate CV4
Mean annual temp				
CC	-4.434	4.110	7.292	.958
SCC	-.956	-.017	-.159	-.096
Mean Jan temp				
CC	2.015	-2.705	-6.069	4.931
SCC	-.856	.246	-.392	-.071
Mean July temp				
CC	1.736	-2.309	-2.369	-4.050
SCC	-.798	-.546	.077	-.132
Mean annual precip				
CC	.357	.216	.321	-.438
SCC	-.222	.805	.054	-.078
Annual temp range				
CC	-.124	-.435	-.098	4.388
SCC	.411	-.695	.552	.198

3 is most heavily weighted by mean January temperature and annual temperature range. Canonical variate 4 is most heavily weighted by annual temperature range.

Discussion – Canonical Correlation

In the female subsample, the first canonical correlation shows a relationship between epiphyseal size, distal limb segment length, and temperature. This correlation demonstrates a relationship between cold temperatures, short distal segment lengths, and increased femoral and humeral head size. This correlation mirrors the expected patterns predicted by Bergmann's and Allen's rules.

The second canonical correlation in the females subsample reflects a connection between an overall increase in size, as measured by limb lengths and the humeral and femoral head breadths, and July temperature, precipitation, and annual temperature range. A relationship exists between overall smaller body size and cold July temperature, low rainfall, and a small annual temperature range. This could reflect that decreased body size, often taken as an indicator of adaptation to climate, may also be associated with decreased food resources availability as it relates to low precipitation levels.

The third canonical correlation for females shows a relationship between leg length, humerus head breadth, and precipitation and annual temperature range. The third correlation shows that long legs and small humerus heads are correlated with low precipitation and a large annual temperature range. The fourth canonical correlation reflects a relationship between humerus and tibia length and annual temperature range, with the lengths increasing as the temperature range grows.

In the male subsample, the first canonical correlation reflects a relationship between the lengths of the humerus, radius, and tibia, femur head breadth, and temperature. As temperature increases, the bone lengths decrease and femoral head breadth increases. This relationship is similar to that seen in the first canonical correlations in the female subsample.

The components of the second canonical correlation for males mirror those of the third canonical correlation in females, with the addition of mean July temperature as a significant component of the second metric canonical variate. This correlation describes a relationship between increased humerus head size, decreased leg length, cold July temperature, high precipitation, and large annual temperature range. These relationships are similar to those seen in females, with long legs and decreased humerus size being associated with low precipitation. However, in males large annual temperature range is related to short legs, while females show the opposite trend. This might be indicative of annual temperature range having no consistent effect on these six osteometric measurements.

The third canonical correlation for males show a relationship between overall size, January temperature, and annual temperature range. Overall size increases with large annual temperature range and cold January temperature. This is similar to the relationships seen in the second canonical correlation in females, who show an increase in overall size with an increase in annual temperature range. Females show a decrease in size with cold July temperatures while males show an increase in size with cold January temperatures. While the two relationships may not be directly comparable, they suggest opposite trends for decreased temperature and overall size between the sexes.

The fourth canonical correlation for males demonstrates a weak connection between humerus head breadth and annual temperature range, where head breadth decreases as the annual temperature range grows.

Conclusion

Multiple regression and canonical correlation produced results that largely supported the findings of the univariate analyses. Long bone length was shown to be related to temperature. Some epiphyseal measurements were influenced by climate variables, but not to the same degree the long bone lengths were. Diaphyseal measurements showed no specific trend in r^2 values or in which climate variables contributed significantly to the models. Os coxa measurements were consistently associated with temperature, although the association were not particularly strong.

Chapter 8: The Arctic Effect

Many of the extreme values for the skeletal measurements used in this study derive from the Inuit and Aleut groups. Differences in subsistence strategy and ancestry between these groups and other indigenous North Americans may be impacting the morphology of the Arctic samples in such a manner as to create correlations between measurements and climate data that are not the result of ecogeographical adaptation in North America as a whole.

The Inuit and Aleut samples used in this study are coastal and largely practiced a hunting and gathering subsistence strategy which probably relied heavily on marine foods. The majority of the other samples come from groups who were horticulturalists or agriculturalists, most of whom lived in the interior of the continent. These differences in habitation site and subsistence patterns may be associated with selective pressures not seen in the interior, largely agricultural southern groups.

The Inuit and Aleut groups may derive from a different ancestral stock than other indigenous North American groups. While Ousley (1995) found no reason to consider the Inuit anthropometrically distinct from other indigenous North American groups on the basis of cranial morphology, Greenberg et al. (1986) argued that they comprise a distinct population resulting from a later migration based on dental and linguistic analyses. The present analysis does not require that all samples examined derive from a common stock. However, if the three waves of migration and the dates of colonization proposed by Greenberg et al. (1986) are applicable, then the Inuit and Aleut groups have

been in North America for approximately 5000 year less than any of the American Indian groups.

Despite the comparatively short amount of time the Inuit and Aleut groups may have resided in North America, the ancestral populations of these groups have long been subjected to extreme cold stress. Early Paleo-Eskimo culture appears in North America around 2500 BC. The sudden appearance of a large number of these sites probably represents a late migration into North America of a population that is most likely ancestral to modern Arctic groups. While it has not been established precisely where the Paleo-Eskimo culture originated, it is likely that it originated in Siberia (Wright 1995). If this is the case, the ancestors of recent Inuit and Aleut groups may have been subjected to extremely cold climate conditions for longer than the 4000 years of residence in North America argued by Greenberg et al. (1986). Regardless of the time the ancestors of the Inuit and Aleut have been in North America, these groups are often cited as examples of populations who are biologically adapted to cold climates (i.e. Park 1999, Stanford et al. 2006).

To test if ecogeographical patterns in morphology still exist in North America when the most extremely cold adapted groups are omitted from the analysis, the correlation and linear regression analyses performed in chapter 5 will be repeated with these sites excluded. This second series of tests will not include the four Alaska sites, Kauwerak, Mummy Caves, St. Michael, Umnak Island, and Native Point in Nunavut. Other than these exclusions, the materials and methods of this chapter will be the same as those used in chapter 5.

Results

Removing the Inuit and Aleut samples from the analysis did have a notable impact on the correlations and linear regressions. Some measurements lost their original strongest correlations and some changed in value. Other correlations increased in strength. The reanalysis also produced differences in the male and female subsamples that were not present in the first run. Pearson correlations between each measurement and climate variable can be seen in tables 8.1, 8.2, and 8.3. P-values for the slopes of the linear regressions of individual measurements on climate variables are available in tables 8.4, 8.5, and 8.6.

In the original analysis, all long bone lengths were most strongly correlated with mean July temperature for both sexes, with the exception of maximum radius length in males. In the reduced female subsample, humerus maximum length, radius maximum length, clavicle maximum length, femur maximum and bicondylar length, and tibia maximum length were all most strongly correlated with annual temperature range (.296, .429, .339, .368, .345, and .490 respectively). Fewer changes were seen in the male subsample. Maximum humerus length, maximum and bicondylar femur length, and maximum tibia length remained most strongly associated with mean July temperature, although the correlations were weaker than those from the first analysis. Radius maximum length remained most strongly correlated with mean annual temperature, though it too was weaker. Only clavicle maximum length changed, becoming more strongly correlated with mean July temperature than mean annual temperature.

The contradictory patterns in the male and female subsamples appeared to negate each other when the combined sample was analyzed. The maximum lengths of the

Table 8.1. Pearson correlations, climate variables and raw data, females.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	-.010	-.212	.147	.225	.296	.273
max diam midshaft	-.190	-.155	-.174	.107	.041	.157
min diam midshaft	-.043	-.158	.022	.303	.159	.311
max vertical head diam	-.159	-.349	.019	.268	.343	.513
epicondylar br	-.214	-.358	-.033	.222	.307	.470
Radius						
max length	-.066	-.323	.208	.172	.429	.324
ML diam midshaft	-.066	-.174	.006	.284	.163	.315
AP diam midshaft	-.169	-.281	.036	.081	.270	.273
max head br	-.237	-.471	.128	.122	.467	.506
Clavicle						
max length	-.096	-.289	.155	.141	.339	.330
SI diam midshaft	.005	-.165	.148	.253	.220	.299
AP diam midshaft	-.078	-.167	.007	.242	.147	.263
Femur						
max length	.027	-.237	.238	.191	.368	.271
bicondylar length	.054	-.205	.248	.221	.345	.263
AP diam midshaft	-.062	-.222	.106	.169	.261	.273
ML diam midshaft	-.157	-.291	-.014	.233	.254	.409
circumf midshaft	-.158	-.349	.070	.219	.352	.446
max head br	-.112	-.366	.133	.274	.415	.513
AP subtroch diam	-.076	-.274	.118	.201	.323	.373
ML subtroch diam	-.080	-.234	.042	.252	.241	.400
epicondylar br	-.154	-.375	.105	.162	.418	.451
Tibia						
max length	-.126	-.408	.221	.058	.490	.296
max epiphyseal br proximal	-.398	-.630	.217	-.032	.696	.604
max epiphyseal br distal	-.226	-.445	.083	.226	.427	.559
max diam nutrient foramen	-.068	-.238	.136	.075	.300	.270
ML diam nutrient foramen	.021	-.213	.168	.314	.297	.325
circumf nutrient foramen	-.042	-.286	.192	.187	.376	.357
Os Coxa						
max length	-.139	-.417	.216	.145	.544	.486
iliac breadth	-.323	-.542	.033	.183	.533	.653

Table 8.2. Pearson correlations, climate variables and raw data, males.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	.234	.160	.240	.102	-.028	-.155
max diam midshaft	-.262	-.184	-.399	.331	-.060	.408
min diam midshaft	-.295	-.227	-.372	.273	.014	.446
max vertical head diam	-.150	-.157	-.205	.272	.048	.344
epicondylar br	-.172	-.144	-.259	.250	-.009	.294
Radius						
max length	.454	.360	.407	.130	-.159	-.316
ML diam midshaft	-.251	-.203	-.347	.312	.008	.410
AP diam midshaft	-.061	-.031	-.194	.406	-.102	.253
max head br	-.107	-.137	-.166	.295	.057	.337
Clavicle						
max length	.213	.152	.251	.034	-.020	-.091
SI diam midshaft	.056	.053	-.004	.282	-.075	.118
AP diam midshaft	-.054	.000	-.157	.243	-.119	.139
Femur						
max length	.098	-.022	.241	-.083	.205	-.122
bicondylar length	.119	.002	.255	-.074	.186	-.129
AP diam midshaft	-.115	-.141	-.046	.002	.142	.095
ML diam midshaft	-.275	-.268	-.261	.158	.139	.349
circumf midshaft	-.240	-.248	-.187	.059	.168	.276
max head br	-.317	-.325	-.281	.127	.194	.450
AP subtroch diam	-.169	-.188	-.110	.016	.154	.228
ML subtroch diam	-.133	-.171	-.140	.229	.108	.293
epicondylar br	-.217	-.239	-.200	.149	.167	.345
Tibia						
max length	.310	.169	.443	-.134	.106	-.320
max epiphyseal br proximal	-.033	-.143	.108	.031	.259	.212
max epiphyseal br distal	-.355	-.414	-.277	.142	.353	.513
max diam nutrient foramen	.110	.048	.136	.069	.035	-.063
ML diam nutrient foramen	-.233	-.261	-.173	.092	.204	.241
circumf nutrient foramen	.007	-.067	.071	.084	.136	.060
Os Coxa						
max length	-.321	-.363	-.286	-.022	.327	.396
iliac breadth	-.296	-.350	-.229	-.084	.363	.387

Table 8.3. Pearson correlations, climate variables and z-scores, sexes pooled.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	.011	-.155	.118	.115	.211	.147
max diam midshaft	-.162	-.061	-.265	.254	-.117	.256
min diam midshaft	-.047	-.033	-.130	.325	-.055	.320
max vertical head diam	-.178	-.250	-.129	.281	.128	.458
epicondylar br	-.203	-.213	-.178	.247	.064	.388
Radius						
max length	-.064	-.253	.120	.066	.300	.229
ML diam midshaft	-.097	-.089	-.166	.366	-.026	.348
AP diam midshaft	-.088	-.095	-.134	.282	.000	.290
max head br	-.247	-.339	-.096	.213	.233	.486
Clavicle						
max length	.028	-.136	.164	.039	.213	.195
SI diam midshaft	.023	-.053	.007	.270	.048	.285
AP diam midshaft	.054	.062	-.072	.262	-.092	.159
Femur						
max length	.069	-.180	.253	.012	.320	.048
bicondylar length	.081	-.163	.255	.025	.307	.050
AP diam midshaft	.024	-.090	.095	.090	.135	.092
ML diam midshaft	-.107	-.161	-.075	.221	.087	.296
circumf midshaft	-.066	-.168	.015	.153	.148	.255
max head br	-.160	-.275	-.041	.222	.204	.432
AP subtroch diam	-.003	-.125	.074	.111	.154	.222
ML subtroch diam	-.142	-.234	-.067	.240	.156	.380
epicondylar br	-.200	-.290	-.060	.166	.221	.397
Tibia						
max length	-.040	-.308	.270	-.122	.442	.067
max epiphyseal br proximal	-.279	-.457	.145	.004	.481	.458
max epiphyseal br distal	-.277	-.407	-.047	.212	.328	.523
max diam nutrient foramen	-.044	-.171	.088	.050	.205	.156
ML diam nutrient foramen	-.008	-.152	.064	.213	.172	.194
circumf nutrient foramen	-.042	-.218	.118	.119	.265	.231
Os Coxa						
max length	-.199	-.345	-.008	.091	.340	.400
iliac breadth	-.275	-.414	-.032	.067	.391	.504

Table 8.4. P-values, significance test for slope of regression lines, females.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	.881	.001	.022	<.001	<.001	<.001
max diam midshaft	.002	.011	.004	.096	.502	.010
min diam midshaft	.486	.010	.725	<.001	.009	<.001
max vertical head diam	.013	<.001	.773	<.001	<.001	<.001
epicondylar br	.001	<.001	.627	.001	<.001	<.001
Radius						
max length	.334	<.001	.002	.012	<.001	<.001
ML diam midshaft	.323	<.001	.930	<.001	.014	<.001
AP diam midshaft	.016	.009	.615	.250	<.001	<.001
max head br	.001	<.001	.089	.104	<.001	<.001
Clavicle						
max length	.240	<.001	.058	.085	<.001	<.001
SI diam midshaft	.948	<.001	.057	.001	.004	<.001
AP diam midshaft	.319	.034	.933	.002	.061	.001
Femur						
max length	.672	.033	<.001	.003	<.001	<.001
bicondylar length	.415	<.001	<.001	.001	<.001	<.001
AP diam midshaft	.323	.002	.090	.007	<.001	<.001
ML diam midshaft	.011	<.001	.826	<.001	<.001	<.001
circumf midshaft	.013	<.001	.274	.001	<.001	<.001
max head br	.080	<.001	.039	<.001	<.001	<.001
AP subtroch diam	.181	<.001	.036	<.001	<.001	<.001
ML subtroch diam	.161	<.001	.458	<.001	<.001	<.001
epicondylar br	.044	<.001	.169	.034	<.001	<.001
Tibia						
max length	.064	<.001	.001	.394	<.001	<.001
max epiphyseal br proximal	<.001	<.001	.014	.710	<.001	<.001
max epiphyseal br distal	.002	<.001	.269	.002	<.001	<.001
max diam nutrient foramen	.260	<.001	.024	.212	<.001	<.001
ML diam nutrient foramen	.728	<.001	.004	<.001	<.001	<.001
circumf nutrient foramen	.491	<.001	.002	.002	<.001	<.001
Os Coxa						
max length	.107	<.001	.011	.091	<.001	<.001
iliac breadth	<.001	<.001	.729	.049	<.001	<.001

Table 8.5. P-values, significance test for slope of regression lines, males.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	<.001	.006	<.001	.082	.633	.008
max diam midshaft	<.001	.001	<.001	<.001	.293	<.001
min diam midshaft	<.001	<.001	<.001	<.001	.804	<.001
max vertical head diam	.008	.005	<.001	<.001	.406	<.001
epicondylar br	.004	.017	<.001	<.001	.881	<.001
Radius						
max length	<.001	<.001	<.001	.036	.010	<.001
ML diam midshaft	<.001	.001	<.001	<.001	.898	<.001
AP diam midshaft	.319	.612	.001	<.001	.097	<.001
max head br	.137	.056	.020	<.001	.433	<.001
Clavicle						
max length	.003	.032	<.001	.632	.783	.204
SI diam midshaft	.419	.433	.948	<.001	.273	.083
AP diam midshaft	.421	.999	.020	<.001	.080	.039
Femur						
max length	.091	.705	<.001	.150	<.001	.035
bicondylar length	.042	.975	<.001	.204	.001	.027
AP diam midshaft	.038	.011	.404	.971	.010	.087
ML diam midshaft	<.001	<.001	<.001	.004	.012	<.001
circumf midshaft	<.001	<.001	.001	.291	.003	<.001
max head br	<.001	<.001	<.001	.033	.001	<.001
AP subtroch diam	.001	<.001	.038	.770	.004	<.001
ML subtroch diam	.012	.001	.008	<.001	.042	<.001
epicondylar br	.002	.001	.004	.031	.017	<.001
Tibia						
max length	<.001	.005	<.001	.027	.081	<.001
max epiphyseal br proximal	.687	.081	.189	.707	.001	.009
max epiphyseal br distal	<.001	<.001	<.001	.050	<.001	<.001
max diam nutrient foramen	.047	.389	.014	.213	.532	.255
ML diam nutrient foramen	<.001	<.001	.002	.095	<.001	<.001
circumf nutrient foramen	.904	.234	.206	.137	.016	.285
Os Coxa						
max length	<.001	<.001	<.001	.775	<.001	<.001
iliac breadth	<.001	<.001	.005	.312	<.001	<.001

Table 8.6. P-values, significance test for slope of regression lines, pooled sample.

Measurement	Annual Temp	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Humerus						
max length	.804	<.001	.007	.009	<.001	.001
max diam midshaft	<.001	.149	<.001	<.001	.006	<.001
min diam midshaft	.271	.440	.002	<.001	.195	<.001
max vertical head diam	<.001	<.001	.003	<.001	.003	<.001
epicondylar br	<.001	<.001	<.001	<.001	.168	<.001
Radius						
max length	.171	<.001	.010	.156	<.001	<.001
ML diam midshaft	.033	.050	<.001	<.001	.567	<.001
AP diam midshaft	.062	.044	.005	<.001	>.999	<.001
max head br	<.001	<.001	.070	<.001	<.001	<.001
Clavicle						
max length	.612	.014	.003	.484	<.001	<.001
SI diam midshaft	.664	.314	.898	<.001	.361	<.001
AP diam midshaft	.302	.238	.172	<.001	.079	.002
Femur						
max length	.113	<.001	<.001	.791	<.001	.278
bicondylar length	.067	<.001	<.001	.579	<.001	.261
AP diam midshaft	.562	.032	.024	.033	.001	.028
ML diam midshaft	.011	<.001	.074	<.001	.038	<.001
circumf midshaft	.125	<.001	.720	<.001	.001	<.001
max head br	<.001	<.001	.361	<.001	<.001	<.001
AP subtroch diam	.937	.001	.057	.004	<.001	<.001
ML subtroch diam	<.001	<.001	.087	<.001	<.001	<.001
epicondylar br	<.001	<.001	.256	.001	<.001	<.001
Tibia						
max length	.391	<.001	<.001	.008	<.001	.147
max epiphyseal br proximal	<.001	<.001	.017	.943	<.001	<.001
max epiphyseal br distal	<.001	<.001	.384	<.001	<.001	<.001
max diam nutrient foramen	.292	<.001	.034	.224	<.001	<.001
ML diam nutrient foramen	.838	<.001	.116	<.001	<.001	<.001
circumf nutrient foramen	.319	<.001	.005	.005	<.001	<.001
Os Coxa						
max length	.001	<.001	.896	.129	<.001	<.001
iliac breadth	<.001	<.001	.620	.299	<.001	<.001

humerus, radius, clavicle, femur, and tibia all were most strongly correlated with annual temperature range. The majority of the correlations with annual temperature range seen in the combined sample were weaker than the strongest correlations for maximum bone length within each sex.

The removal of the Inuit and Aleut samples also changed the results of the linear regression between bone length and climate variables. Among females, the regressions of humerus length, radius length, clavicle length, both measures of femur length, and tibia length on mean annual temperature lost their statistical significance. Humerus length, radius length, and clavicle length became statistically significant for annual temperature range. Again, fewer changes were seen in the male subsample. Humerus maximum length lost statistical significance with mean annual precipitation, tibia maximum length lost significance with annual temperature range, and maximum femur length was no longer significant with mean annual temperature. The patterns in the combined sample are very similar to those seen in the female subsample. Overall, bone length is significantly associated with mean July temperature, mean January temperature, and latitude and not correlated with mean annual temperature. Femur length appears to deviate from this pattern in its lack of significance with latitude in the combined sample and mean January temperature in males.

On the whole, measures of epiphyseal size remained most strongly associated with the climate variables they were most correlated with in the initial analysis. In the female subsample, radius head breadth become most strongly associated with latitude and tibia proximal epiphyseal breadth was most strongly associated with annual temperature range, although it retained a strong association with latitude (.604). Many of the

correlations for epiphyseal size in females increased in strength. Among males, humerus epicondylar breadth became most strongly correlated with latitude and, as seen in the females, tibia proximal epiphyseal breadth becomes most closely associated with annual temperature range. The combined sample parallels the patterns seen in the male subsample, with humerus epicondylar breadth most strongly correlated with latitude and tibia proximal epiphyseal breadth most strongly correlated with annual temperature range.

Several changes were seen in the second set of linear regressions. Among females, humerus epicondylar breadth became significant with mean annual temperature, mean January temperature, and annual temperature range. Radius head breadth lost significance with annual precipitation but gained significance with mean annual temperature and mean January temperature. Femur head diameter lost significance with mean annual temperature and became significant with mean July temperature. Femur epicondylar breadth became significant with mean annual precipitation. Tibia proximal epiphyseal breadth became significant with mean July temperature while tibia distal breadth lost its significance with this variable.

Once again, fewer changes were seen in the males. Humerus epicondylar breadth became significant with mean January temperature and lost significance with annual temperature range. Femur epicondylar breadth and tibia proximal epiphyseal breadth gained significance with annual temperature range. In the combined sample, radius head breadth became significant with mean annual temperature and annual temperature range. Tibia proximal epiphyseal breadth became significant with mean July temperature while tibia distal epiphyseal breadth lost significance with the same measure. For both sexes

and the pooled sample, most measures of epiphyseal size were significant for latitude, mean annual precipitation, and mean annual temperature.

Diaphyseal measurements experienced numerous changes in their strongest correlations. In the female subsample, humerus maximum diameter in the midshaft became most strongly correlated with mean annual temperature. Radius anterior-posterior diameter at midshaft was most strongly associated with mean January temperature. Both clavicle midshaft measurements, medial-lateral subtrochanteric diameter of the femur, and medial-lateral diameter of the tibia at the nutrient foramen became most strongly associated with latitude. Among males, humerus maximum diameter at midshaft and medial-lateral subtrochanteric diameter were most strongly correlated with latitude. Anterior-posterior diameter of the femur at midshaft became most strongly correlated with annual temperature range. Maximum diameter of the tibia at the nutrient foramen was most strongly correlated with mean July temperature while medial-lateral diameter of the tibia at the nutrient foramen was most strongly correlated with mean January temperature.

The changes seen in the pooled sample did not closely mirror the patterns seen in either sex. Superior-inferior clavicle diameter, radius anterior-posterior diameter, medial-lateral subtrochanteric diameter of the femur, and medial-lateral diameter of the tibia at the nutrient foramen became most strongly associated with latitude. Two other measurements, humerus minimum midshaft diameter and medial-lateral diameter of the radius at midshaft, were most strongly correlated with mean annual precipitation. Anterior-posterior diameter of the femur at midshaft was most strongly associated with annual temperature range.

Among females, five diaphyseal measurements lost significance with mean annual temperature, while the majority of the remainder were never significant with this variable. Only minimum diameter of the humerus gained significance with this. Six measurements became significant with mean January temperature. Four lost significance with mean July temperature. Such dramatic changes were not seen in the males, with four gaining significance with annual temperature range and two losing it. Two diaphyseal measurements each became significant with mean annual temperature and mean January temperature.

The combined sample demonstrates a much clearer pattern than either sex individually. Five diaphyseal measurements became non-significant with mean annual temperature, three with mean January temperature, and four with mean July temperature. Two measurements each became significant with mean January temperature, mean annual precipitation, and latitude. Overall, only two diaphyseal measures produces non-significant results with latitude, superior-inferior midshaft diameter of the clavicle and anterior-posterior midshaft diameter of the femur, and both of these only in the male subsample.

In both sexes and the combined sample, both measurements from the os coxa are strongly correlated with latitude. The relationship is strongest among females, despite the fact that maximum length is somewhat more strongly correlated with annual temperature range than latitude in this subsample. In the pooled sample, neither measurement produces a significant regression slope with mean July temperature or mean annual precipitation. In females, iliac breadth is marginally significant with mean annual precipitation (.049), while maximum length is significant with mean July temperature and

non-significant with mean annual temperature. Among males, only mean annual precipitation was not significant for either measure.

Discussion

Removing the Inuit and Aleut samples from the data set greatly affected the strength and patterning of the correlations and linear regressions between measurements and climate variables. Long bone lengths lose their clear relationship with mean July temperature, with the correlation weakening in both sexes. Males show a more defined association between increased temperature and long bone length while these measurements in females are more closely related to annual temperature range. While annual temperature range is moderately correlated with mean January temperature (-.635), it is not strongly related to mean annual temperature or mean July temperature (see table 7.7 for correlations among the climate variables). In the reduced sample, males appear to be following the expectations of Allen's rule while females are not experiencing the same degree of lengthening of the extremities in response to heat stress. Scatterplots of humerus length versus latitude (figure 8.1 for females, 8.2 for males), radius length versus latitude (figure 8.3 for females, 8.4 for males), femur length versus latitude (figure 8.5 for females, 8.6 for males), and tibia length versus latitude (figure 8.7 for females, 8.8 for males) demonstrate that the distal limb bones are comparatively shorter in the Arctic groups.

Clavicle length still does not clearly follow any ecogeographical prediction. In males it elongates as temperature increases, counter to what would be expected if clavicle length is clearly related to torso width. The females subsample shows a slight association

Table 8.7. Correlation matrix, climate variables.

	MAT	Jan Temp	July Temp	Annual Precip	Annual Temp Range	Latitude
Mean An. Temp	1.000	.927	.877	.460	-.329	-.912
Jan Temp	.927	1.000	.648	.570	-.635	-.768
July Temp	.877	.648	1.000	.141	.111	-.908
Annual Precip	.460	.570	.141	1.000	-.533	-.249
Annual Temp Range	-.329	-.635	.111	-.533	1.000	.063
Latitude	-.912	-.768	-.908	-.249	.063	1.000

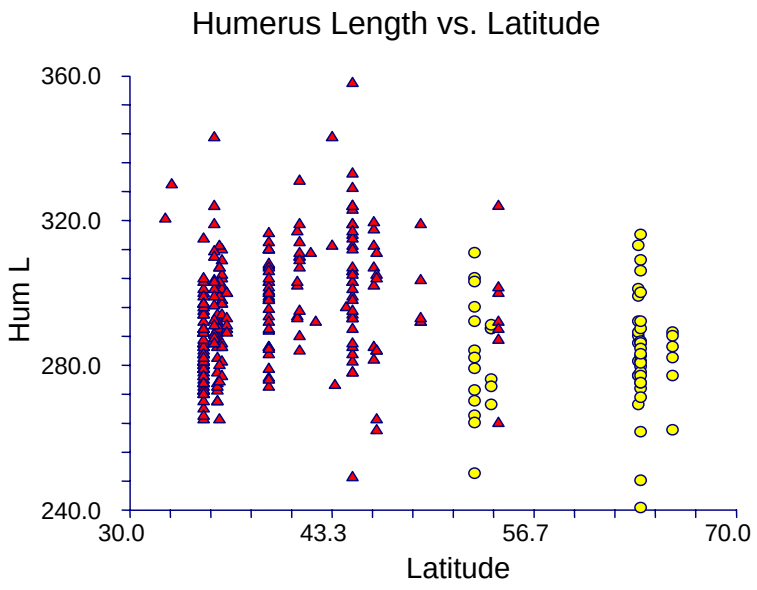


Figure 8.1. Humerus length vs. latitude, females. Yellow circles are Arctic samples, pink triangles are non-Arctic.

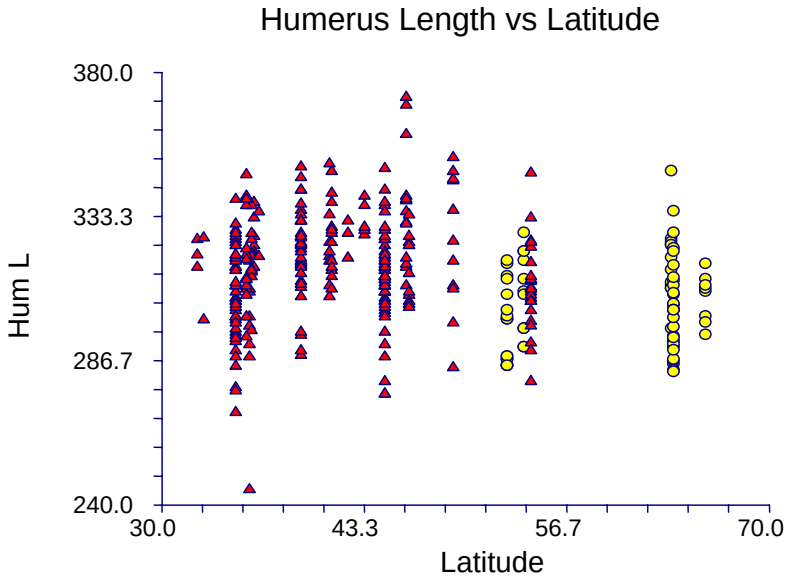


Figure 8.2. Humerus length vs. latitude, males.

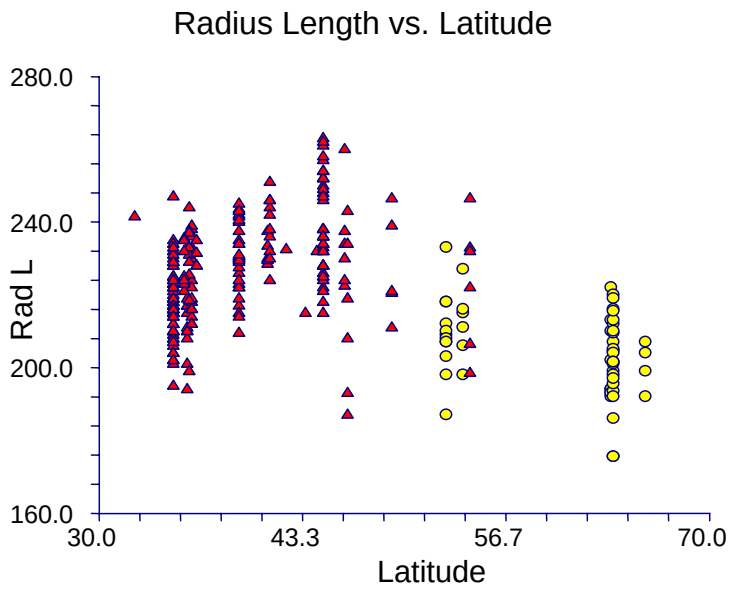


Figure 8.3. Radius length vs. latitude, females.

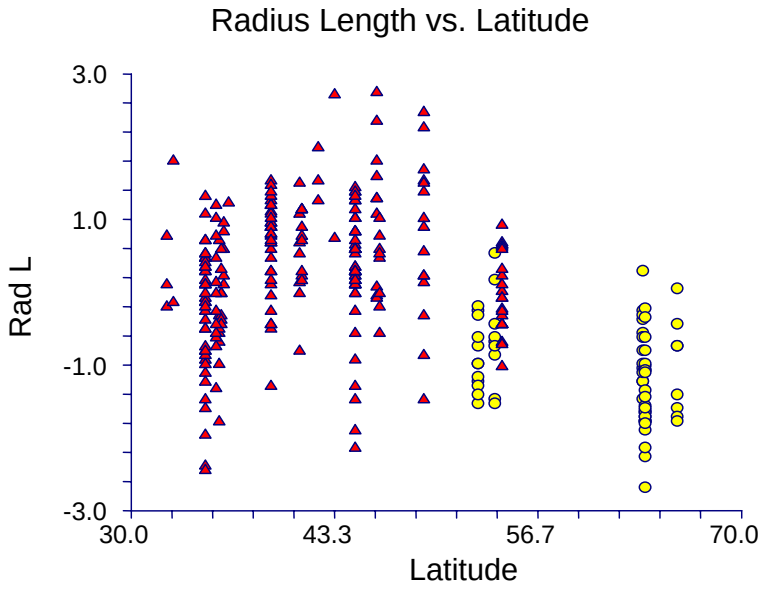


Figure 8.4. Radius length vs. latitude, males.

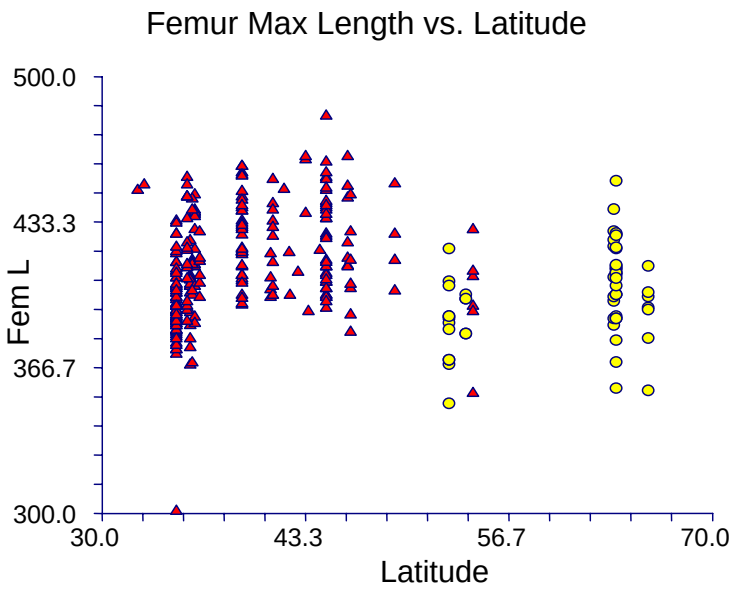


Figure 8.5. Femur length vs. latitude, females.

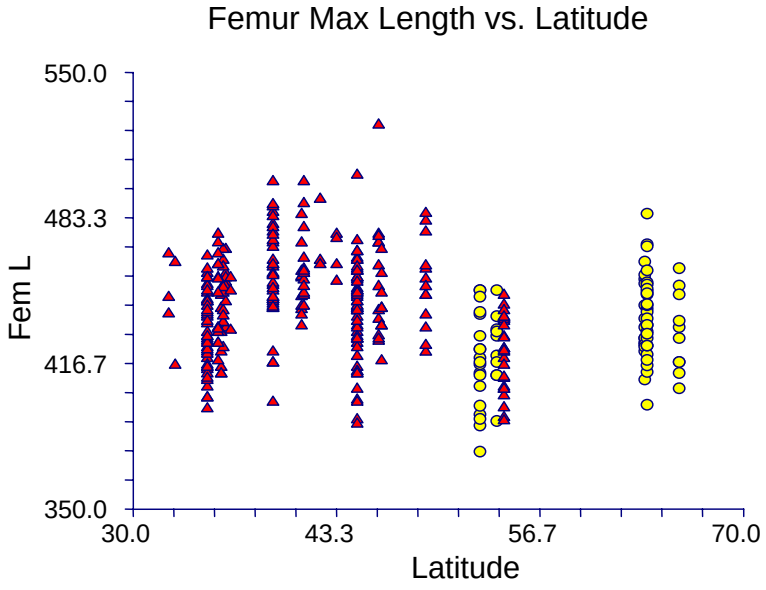


Figure 8.6. Femur length vs. latitude, males.

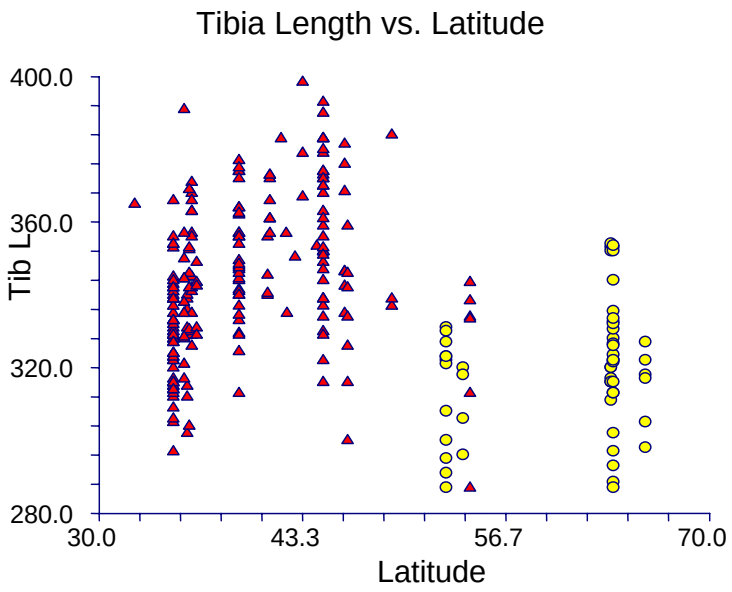


Figure 8.7. Tibia length vs. latitude, females.

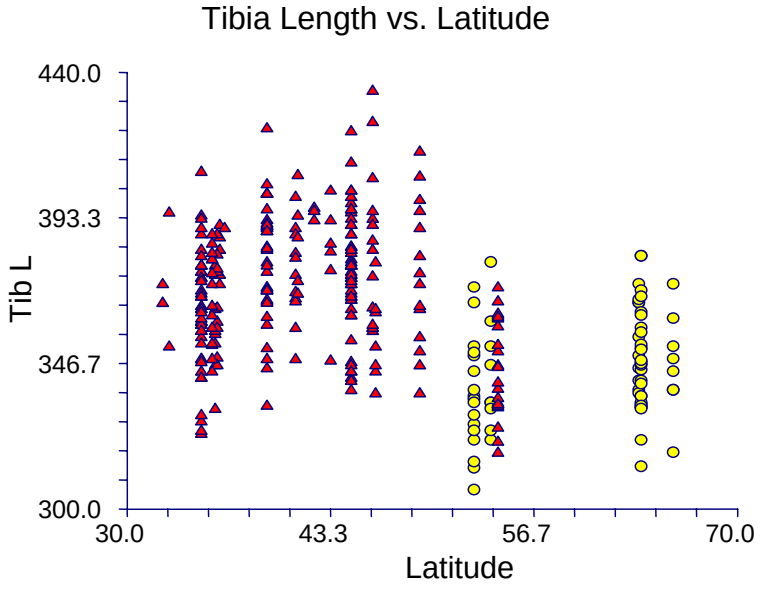


Figure 8.8. Tibia length vs. latitude, males.

between increased clavicle length and decreased mean January temperature, but also show a small increase in clavicle length along with increase mean July temperature. Clavicle length, especially in males, does not appear to be ecogeographically correlated.

Measures of epiphyseal size maintain their high positive correlations with latitude in this second analysis. In many cases, the exclusion of the Arctic samples resulted in drastic increases in the strength of these relationships. This suggests that while the Inuit and Aleuts appear to be cold adapted in their limb lengths and limb segment proportions, these groups do not possess epiphyses as large as would be expected given the extreme cold stress of their environments. A possible explanation for this is that the epiphyses are subject to biomechanical constraints and can only increase to a certain size before they become biomechanically inefficient, if the joint surfaces found in the Arctic groups are among the largest in this sample. The strong correlations between latitude and epiphyseal size seen in the rest of North America supports that these measures are associated with the various climate variables which are subsumed under the latitude variable. Latitude, while it is highly correlated with the three measures of temperature examined in this study, is a complex variable that encompasses several climate features not discussed here which may be influencing these measurements.

In the second analysis, diaphyseal robusticity was positively correlated with latitude for most measurements. Among males, many of the measurements are also correlated with mean July temperature. Some caution should be exercised in totally attributing these positive correlations solely to adaptation to cold stress as diaphyses are also responsive to biomechanical stress (Jones et al. 1977). In addition, several osteometric measurements, including maximum diameter of the humerus at midshaft,

anterior-posterior diameter of the femur at midshaft, and maximum diameter of the tibia at the nutrient foramen, potentially incorporate muscle insertion sites into the measurement, which can be altered in life through repeated biomechanical stress (Kennedy 1989).

Increases in the dimensions of the os coxa were clearly associated with increases in latitude. These relationships were strengthened when the Arctic groups were removed from the data set, suggesting that biomechanical constraints may limit the size of the bony pelvis as well as the size of the epiphyses.

Chapter 9: Comparison with Old World Samples

In order to compare this data set with a mostly Old World sample (which also includes a Koniag sample) studied by Holliday (1997a), brachial and crural indices were calculated for each site. Site means can be found in table 9.1, along with the mean brachial and crural indices by region described by Holliday (1997a).

Holliday (1997a) found a significant, negative correlation between the brachial index and latitude ($r = -.075$) and crural index and latitude ($r = -.88$). The author argued that this is indicative of a decrease in the indices with increasingly colder climates. Correlations between latitude and brachial and crural indices were performed on this data set to determine if similar correlations exist in North America.

Results

The brachial and crural indices in this sample are not as clearly associated with climate as those from Holliday's (1997a) Old World sample. The highest brachial indices in the North American sample exceed those of sub-Saharan Africa. While the majority of the high brachial index values are seen in warmer climates, Huron Village in Michigan produced a high brachial index (.817). The lowest brachial indices were found in the coldest climates. The lowest crural indices were from the sites with the coldest climates. The highest crural indices were found in warm climate sites, Bell-Philhower in New Jersey, and the Sully site in South Dakota.

Table 9.1. Mean brachial and crural indices by site.

Site	BI	CI
North America		
Alaska		
Kauwerak	.744	.795
Mummy Caves	.770	.810
St. Michael	.724	.817
Umnak Island	.754	.808
British Columbia		
Prince Rupert Harbour	.775	.817
Illinois		
Steuben	.778	.826
Manitoba		
Fort Prince of Wales	.770	.799
Souris Valley	.783	.827
Michigan		
Bussinger	.780	.822
Huron Village	.817	.836
Juntunen	.780	.834
Mississippi		
Edwards Mound	.769	.815
Lake George	.820	.850
New Jersey		
Bell-Philhower	.789	.841
New Mexico		
Hawikku	.776	.843
Kwastiyukwa	.807	.829
Pueblo Bonito	.774	.838
Nunavut		
Native Point	.725	.792
Ohio		
Madisonville	.787	.830
Turpin	.774	.832
South Dakota		
Sully	.797	.856
Tennessee		
Dr. Jarman	.765	.824
Thompson Village	.822	.855
Toqua	.762	.821
Washington		
Berrians Island	.782	.814
Old World Regional Averages (from Holliday 1997 AJPA)		
Koniag (“Eskimos”)	.753	.805
Recent Europeans	.750	.827
Recent North Africans	.786	.850
Recent sub-Saharans	.796	.861

The correlation between both indices and latitude is weaker in North America than in Holliday's (1997a) sample. The correlation between brachial index and latitude is -.455. The correlation between crural index and latitude is -.448.

Discussion

The relative length of the proximal and distal limb segments is correlated with latitude in this data set. However, the correlations between latitude and brachial and crural indices are not as strong as these same correlations are in the Old World. This findings suggest that adaptation to climate has occurred in North America since the continent was first settled at the end of the Pleistocene epoch, but that not enough time has elapsed to attain the degree of correlation between limb morphology and latitude seen in the Old World. These findings indicate that the precontact indigenous populations of North America were not as well adapted to climate as populations in the Old World were, suggesting that 13,500 years is not enough time for adaptation to climate to reach the same degree of development that is seen in the Old World.

Chapter 10: Discussion

This goal of this study was to investigate if the patterns of postcranial variation in indigenous North American populations were related to adaptation to climate. Significant relationships between several osteometric measurements and climate variables were found, especially for long bone length, epiphyseal size, and dimensions of the os coxa. This analysis supports the hypothesis that adaptation to climate has occurred in North America since it was first populated, though it is more apparent in some skeletal features than others.

Among the long bones, maximum femur length seems to deviate from the pattern of correlations seen in the other limb bones. Most of the limb bone lengths are positively correlated with mean January temperature, but the femur is not. Perhaps the lack of a relationship between femur length and mean January temperature suggests a biomechanical restraint in femur length, as it is highly correlated with stride length and locomotor efficiency (Wang and Crompton 2003, Witte et al. 1991). This also might explain why tibia length is less strongly correlated with mean January temperature than radius length, despite their being analogous structures and the similar effects of their relative size on the surface area to volume ratio of the body.

The analysis of the shape variables demonstrates that the radius and tibia increase more rapidly with increased temperature than the humerus and femur do. This is in concordance with Holliday's (1999) argument that elongation of the distal limb segments is more adaptive in warm climates than an overall increase in limb length. Multiple

regression analysis further confirmed the strong association between radius and tibia length and temperature.

The "size" variable created from the four limb bones lengths was significantly and positively correlated with mean annual temperature, mean January temperature, and mean July temperature, indicating that an increase in temperature is related to an increase in overall limb bone length. The regressions of the individual shape variables confirm the results of the allometry test, indicating that relative humerus length decreases with an increase in temperature, which is expected if the distal segments increase at a more rapid rate with increased temperature than the proximal segments do.

The significant and mostly positive association between mean annual precipitation and all measurements is not consistent with any ecogeographic expectation. Increased precipitation is related to increased humidity, which, if Ruff's argument that humid conditions are best dealt with through a reduction in overall body size holds true in this sample, then the osteometric variables should be negatively correlated with precipitation (1993). In fact, the opposite pattern in seen.

It is possible that the relationship between increased precipitation and increased size is a nutritional effect. Rainfall is correlated with resource availability, especially in dry environments (Yom-Tov and Geffen 2006). The impact of increased nutrition on overall growth is well documented (i.e. Froehlich 1970, Greulich 1976, Ruff 2002) and can ultimately impact skeletal morphology.

Multivariate analyses demonstrate that limb bone length and some measures of epiphyseal size are well explained by variation in temperature. Generally speaking, mean annual precipitation and annual temperature range are not as influential as mean annual

precipitation, mean January precipitation, and mean July precipitation. All limb bone length and most epiphyseal dimensions respond in a similar manner to climate variables, while diaphyseal measures vary greatly in their relationships with temperature, precipitation, and seasonality.

The Inuit and Aleut groups used in this study appeared to influence the results of the first set of analyses. When the data set was examined with these samples omitted, the relationships between long bone lengths and climate variables weakened, suggesting that the Arctic populations are particularly subject to Allen's rule and, perhaps, those groups south of the Arctic do not exhibit the degree of morphological adaptation predicted by Allen's rule. This pattern was especially prevalent among females.

Omitting the Arctic samples from the data set resulted in increases in the strength of the relationships between climate variables and epiphyseal size and measurements of the os coxa. Biomechanical constraints are possibly influencing the size of these features in Arctic groups. If climate variables were the only factors contributing to morphology, then the Inuit and Aleut groups should possess larger epiphyseal dimensions and os coxae than are observed. However, an unlimited increase in the size of these features could result in lowered biomechanically efficiency and locomotor stability. The morphology of these features in Arctic groups appear to be a comprise between biomechanical demands and adaptation to cold stress.

The pattern of brachial and crural indices is similar to what would be expected if long term adaptation were to have occurred in this sample. However, a number of groups appear to have distal limb segments that are much shorter or longer than would be expected. This suggests that while some climate related patterning has developed in

North America, the peopling of the Americas occurred too recently for the patterns seen in the Old World to become established. Additional factors, such as long distance migrations and possible continued gene flow from Asia may contribute to the deviations from expected patterns.

Are these patterns indicative of biological adaptation?

The analyses performed in this study demonstrate that there is an appreciable relationship between postcranial morphology and climate variables among the late prehistoric inhabitants of North America. However, correlation among sets of variables does not prove a causal relationship exists. Nor does it prove if the correlations are the product of biological adaptation, as Bergmann and Allen argued, physiological effects, as Serrat et al. (2007) claim is inducible in mice, or if they are the result of stochastic processes working on a small founding population.

This study suggests that these patterns in postcranial morphology are strongly related to variation in temperature and precipitation, regardless of the mechanism. Due to the fact that similar patterns can be found in Old World human populations and in many non-human species, the possibility that these changes reflect biological adaptation cannot be excluded.

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APPENDIX

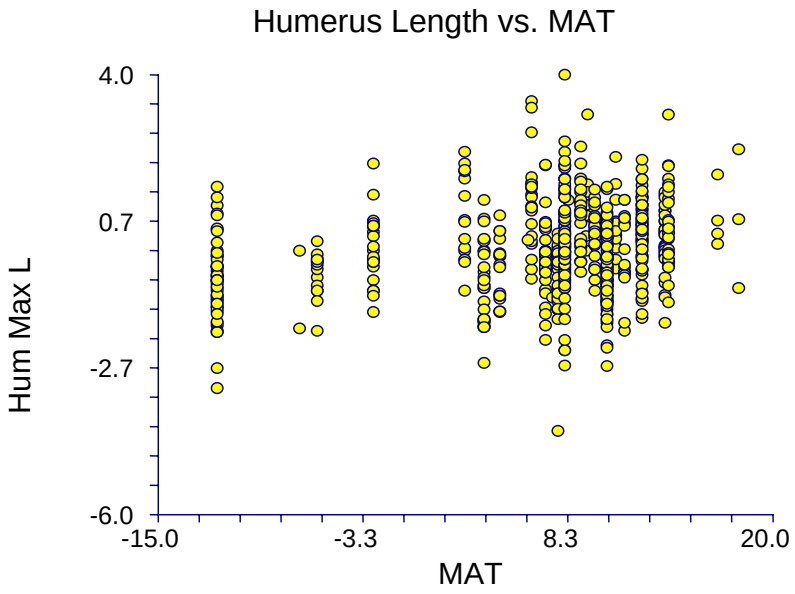


Figure A.1. Humerus length vs. mean annual temperature.

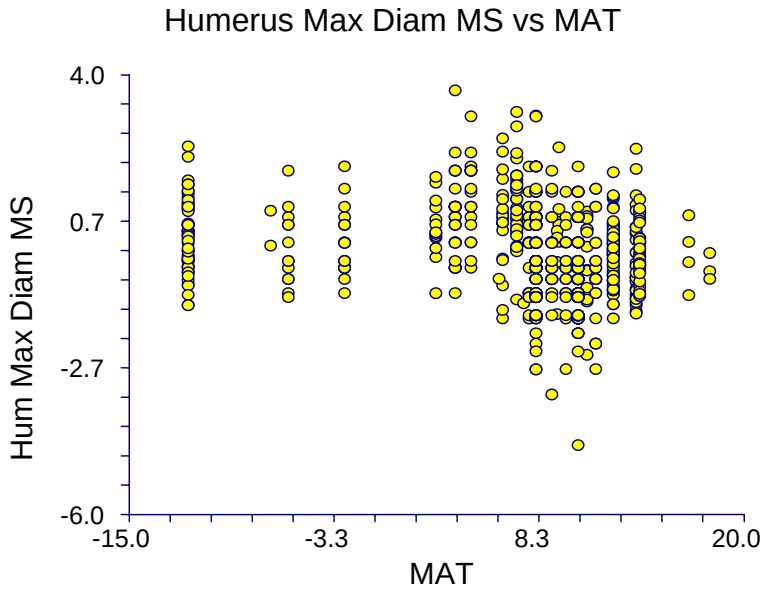


Figure A.2. Humerus maximum diameter at midshaft vs. mean annual temperature.

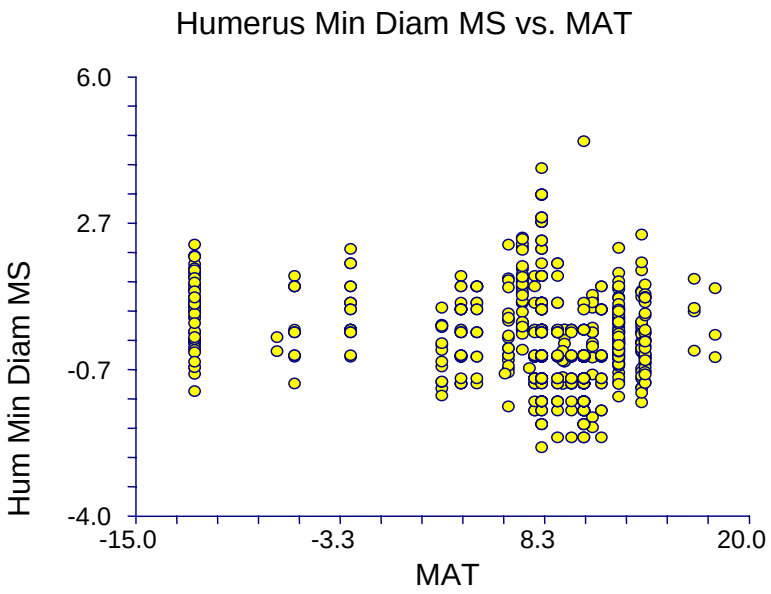


Figure A.3. Humerus minimum diameter at midshaft vs. mean annual temperature.

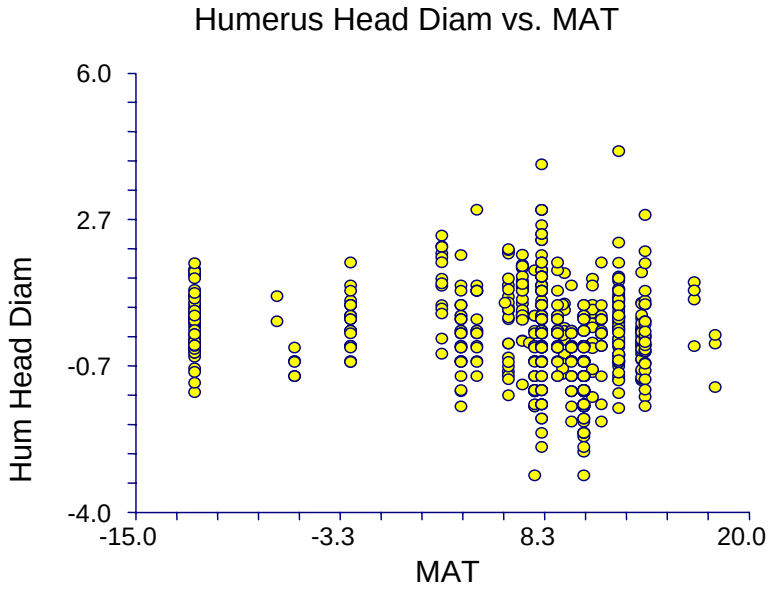


Figure A.4. Humerus head diameter vs. mean annual temperature.

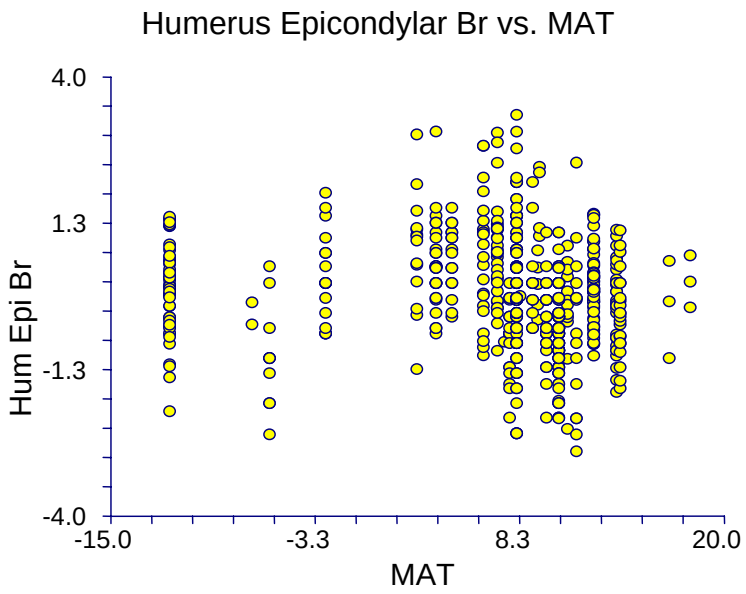


Figure A.5. Humerus epicondylar breadth vs. mean annual temperature.

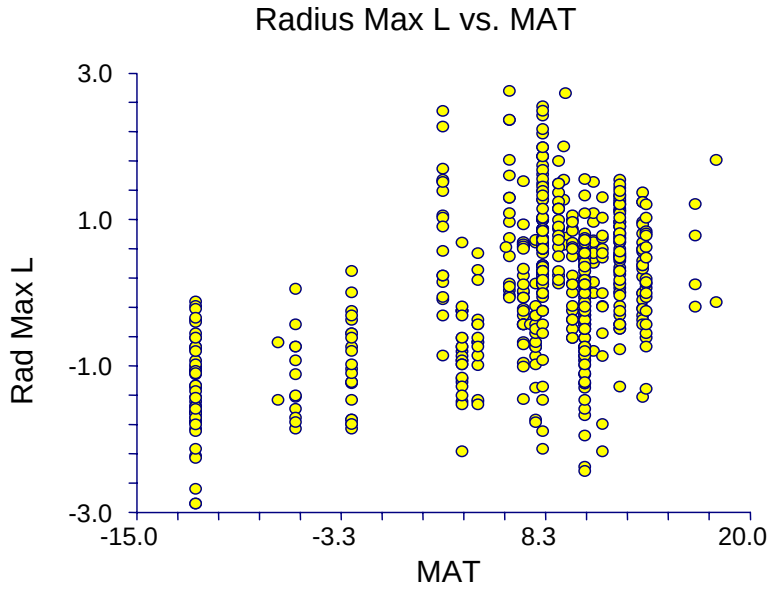


Figure A.6. Radius maximum length vs. mean annual temperature.

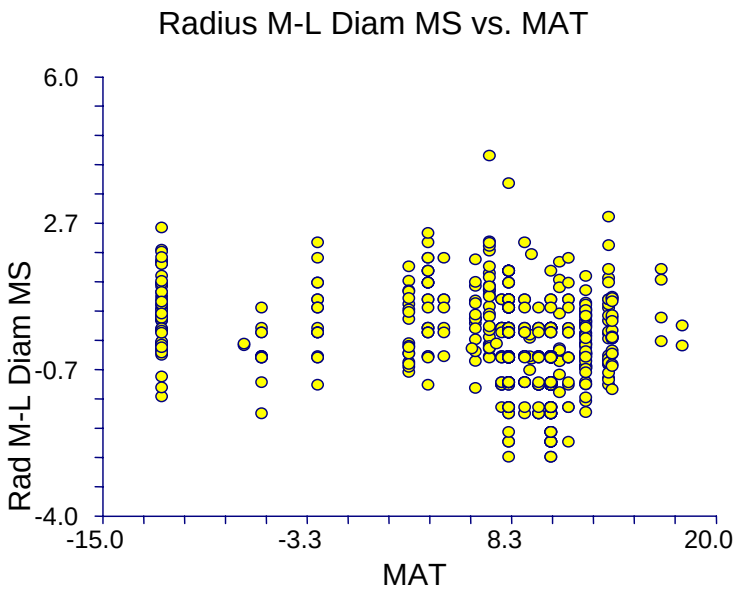


Figure A.7. Radius medial-lateral diameter at midshaft vs. mean annual temperature.

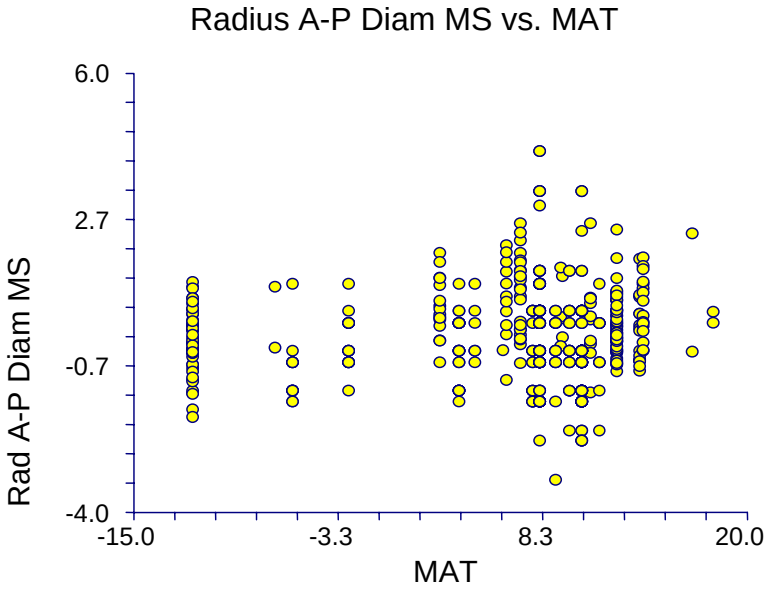


Figure A.8. Radius anterior-posterior diameter at midshaft vs. mean annual temperature.

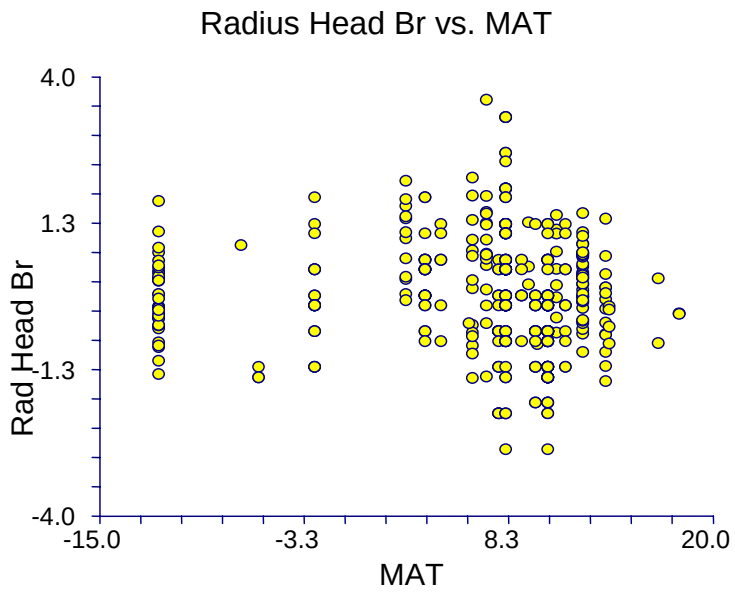


Figure A.9. Radius maximum head breadth vs. mean annual temperature.

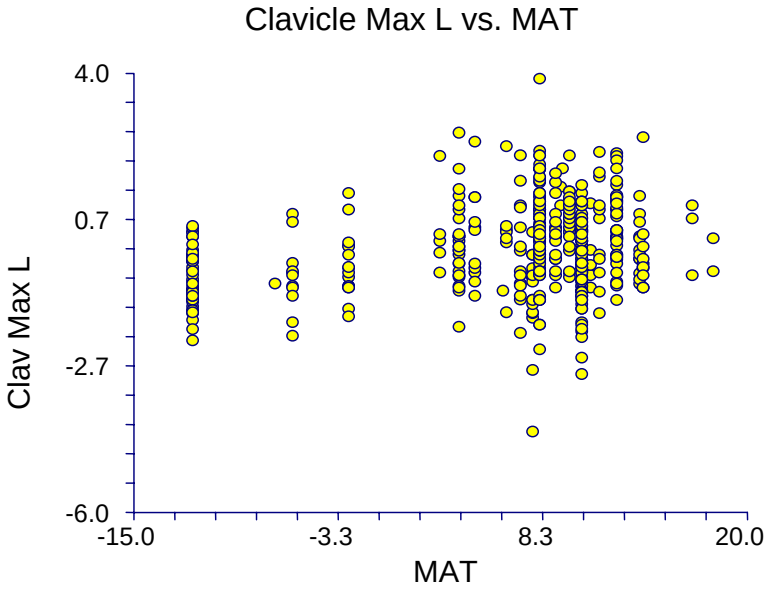


Figure A.10. Clavicle maximum length vs. mean annual temperature.

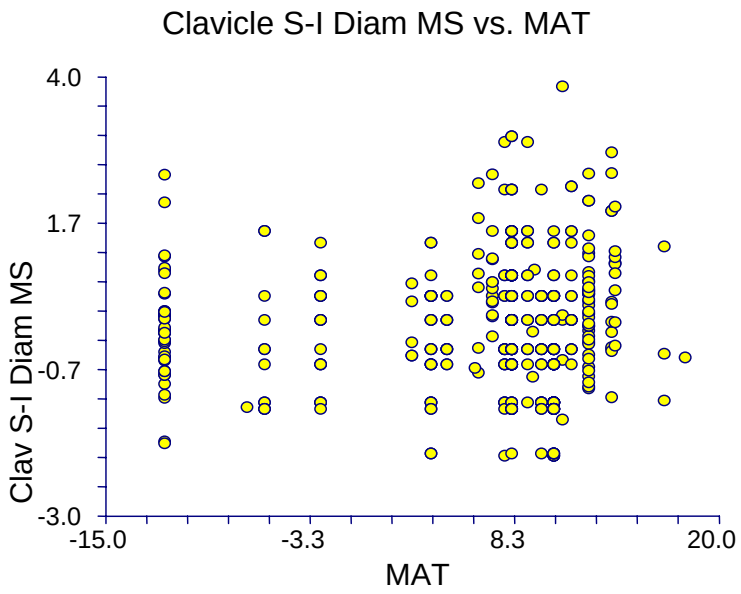


Figure A.11. Clavicle superior-inferior diameter at midshaft vs. mean annual temperature.

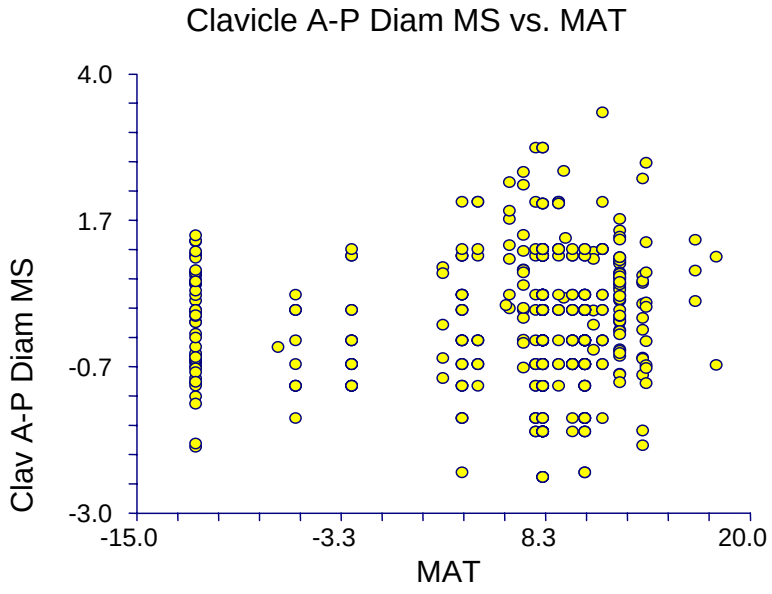


Figure A.12. Clavicle anterior-posterior diameter at midshaft vs. mean annual temperature.

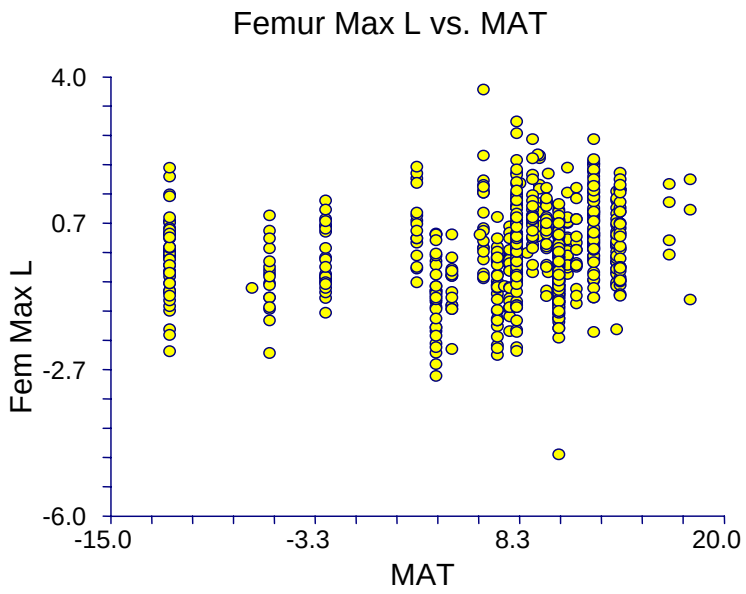


Figure A.13. Femur maximum length vs. mean annual temperature.

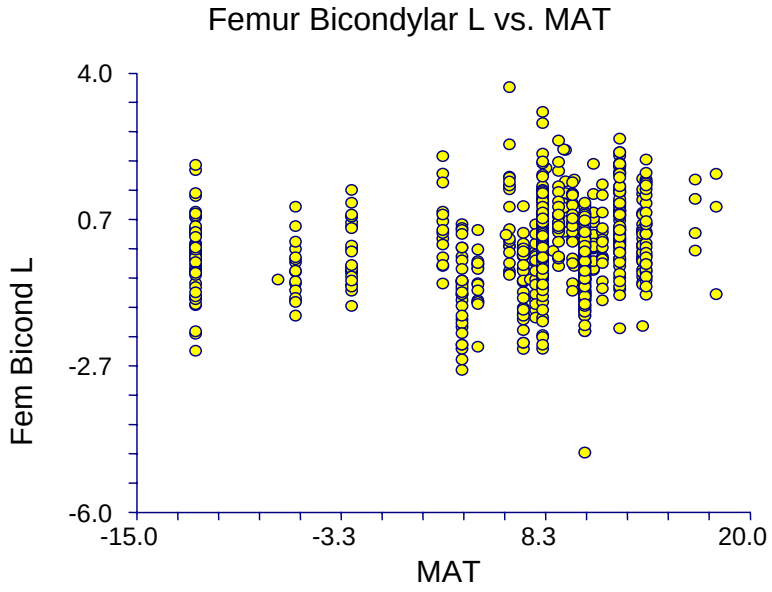


Figure A.14. Femur bicondylar length vs. mean annual temperature.

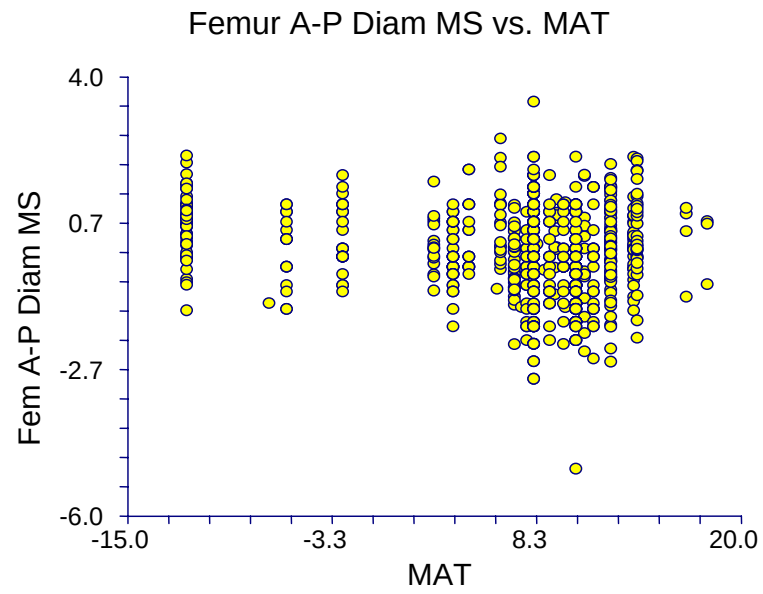


Figure A.15. Femur anterior-posterior diameter at midshaft vs. mean annual temperature.

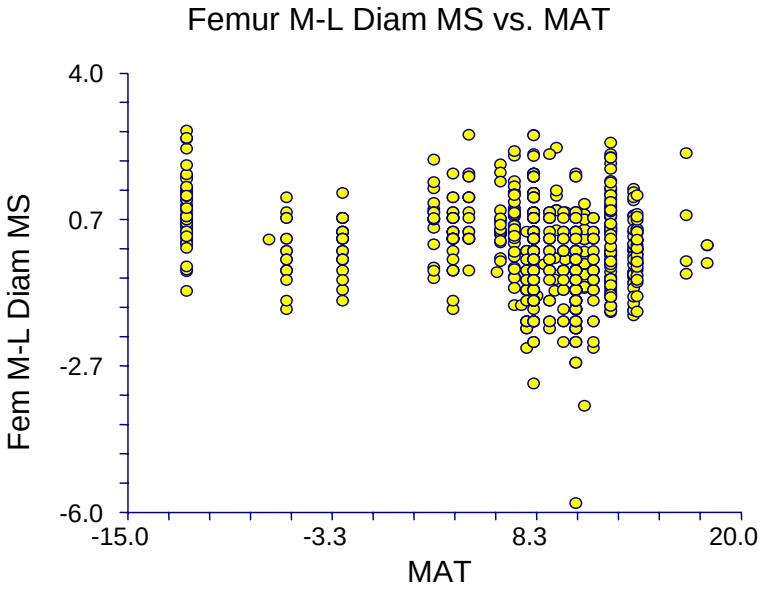


Figure A.16. Femur medial-lateral diameter at midshaft vs. mean annual temperature.

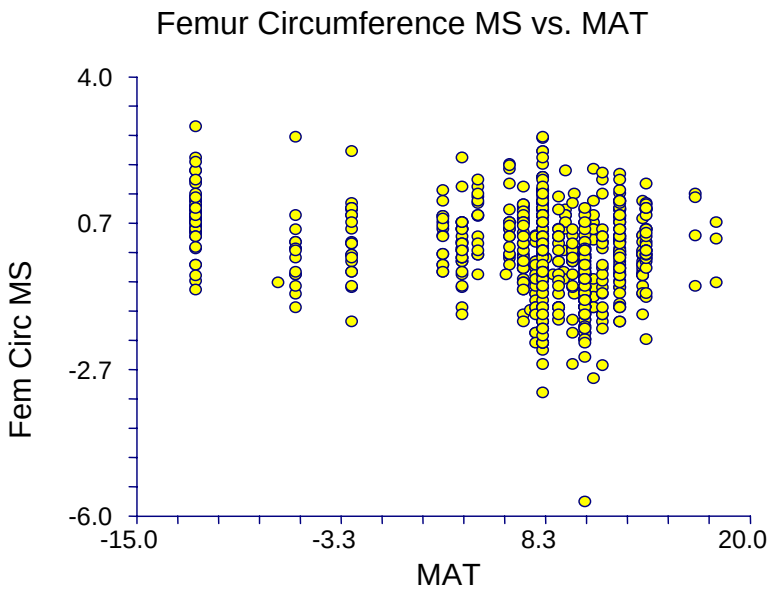


Figure A.17. Femur circumference at midshaft vs. mean annual temperature.

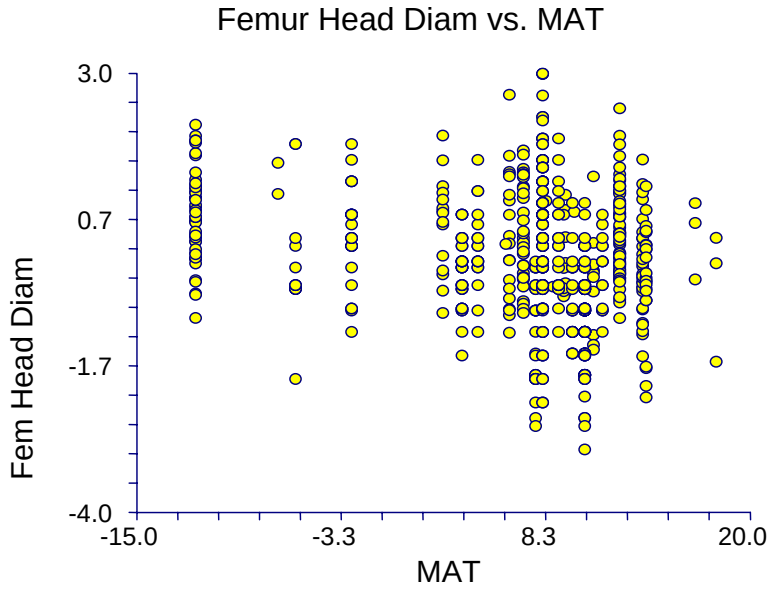


Figure A.18. Femur head diameter vs. mean annual temperature.

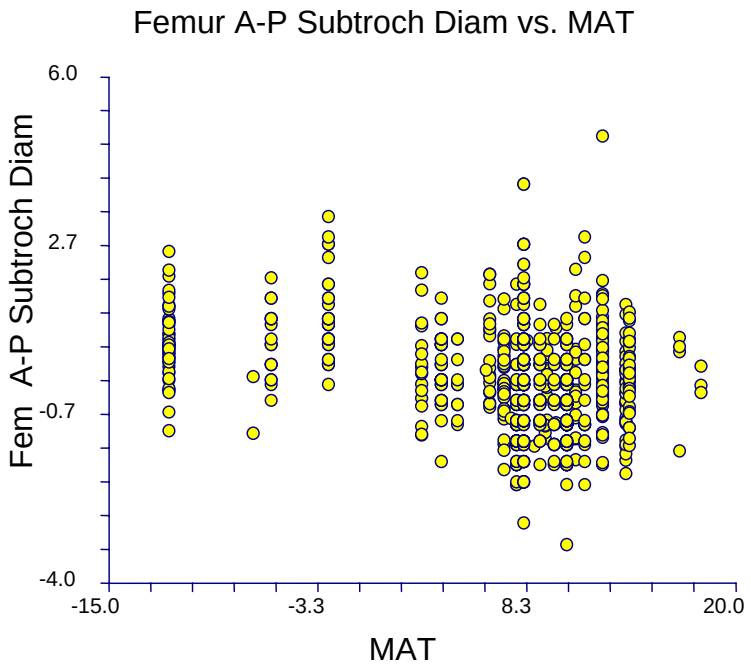


Figure A.19. Femur anterior-posterior subtrochanteric diameter vs. mean annual temperature.

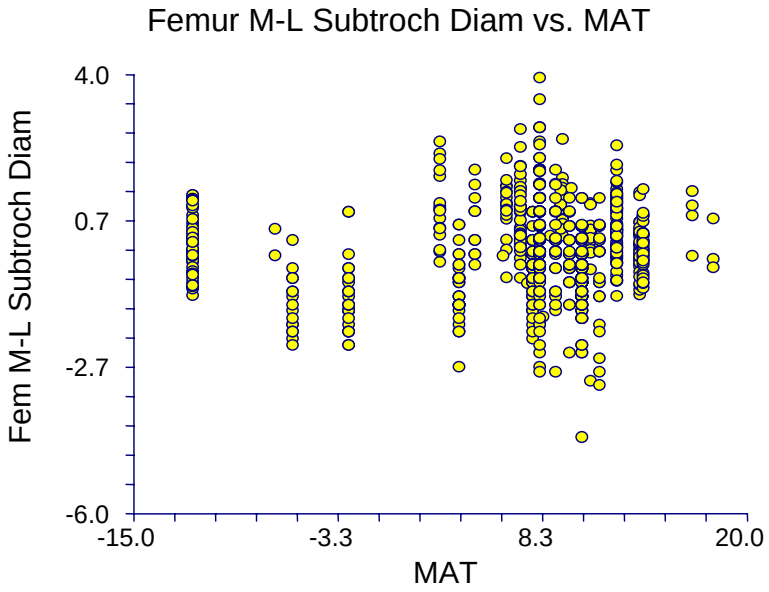


Figure A.20. Femur medial-lateral subtrochanteric diameter vs. mean annual temperature.

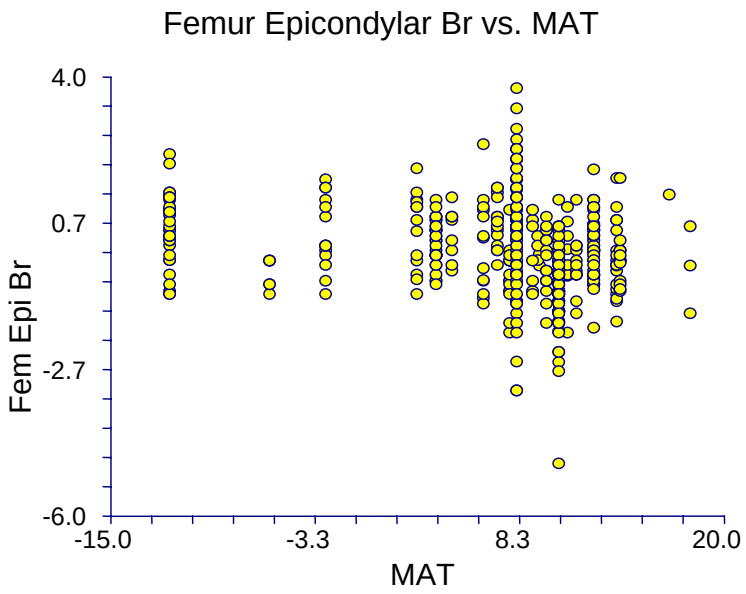


Figure A.21. Femur epicondylar breadth vs. mean annual temperature.

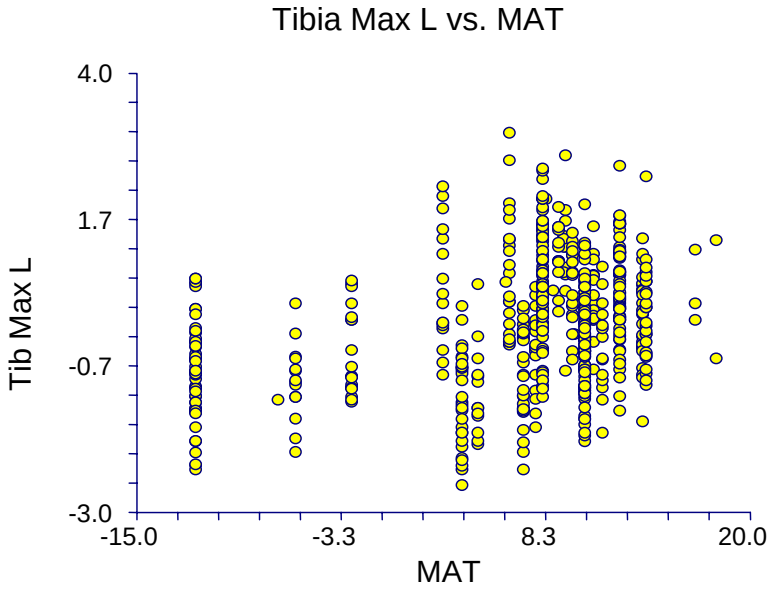


Figure A.22. Tibia maximum length vs. mean annual temperature.

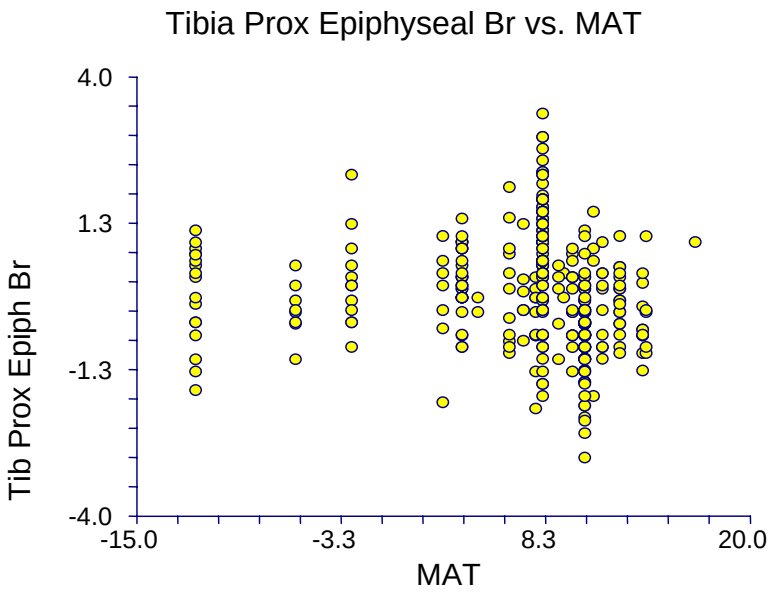


Figure A.23. Tibia proximal epiphyseal breadth vs. mean annual temperature.

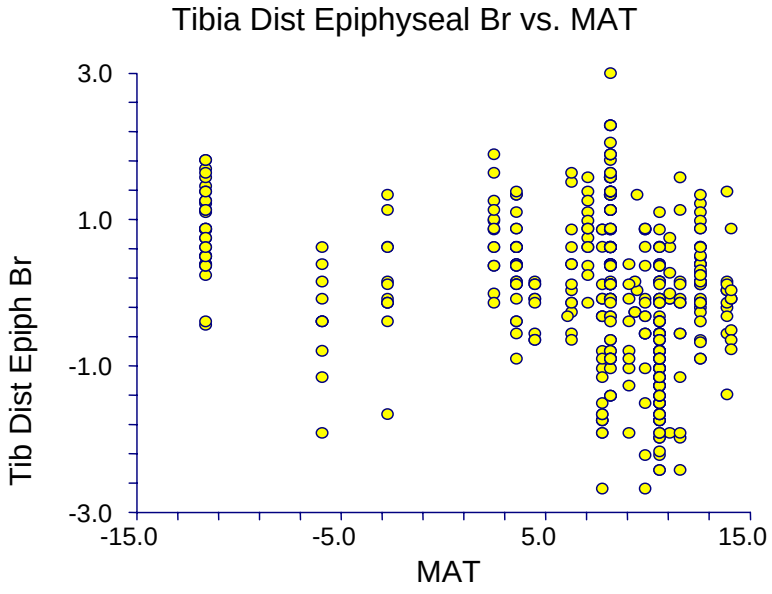


Figure A.24. Tibia distal epiphyseal breadth vs. mean annual temperature.

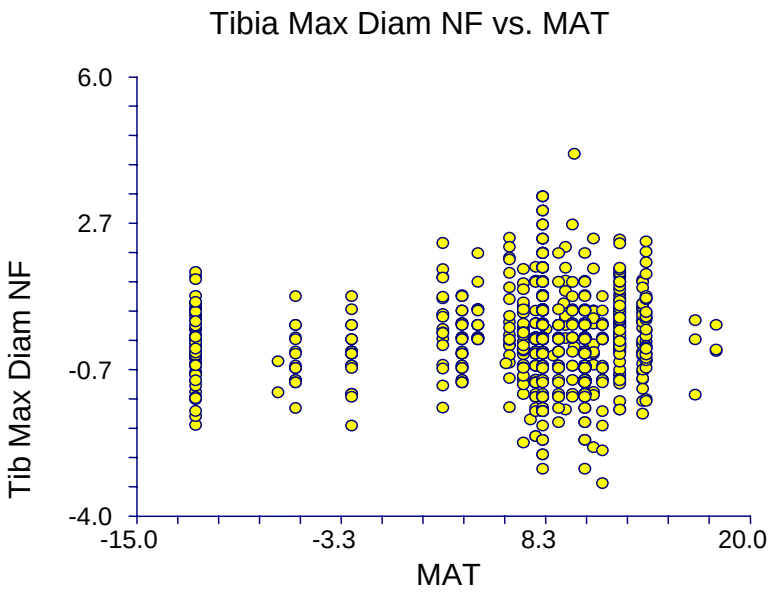


Figure A.25. Tibia maximum diameter at the nutrient foramen vs. mean annual temperature.

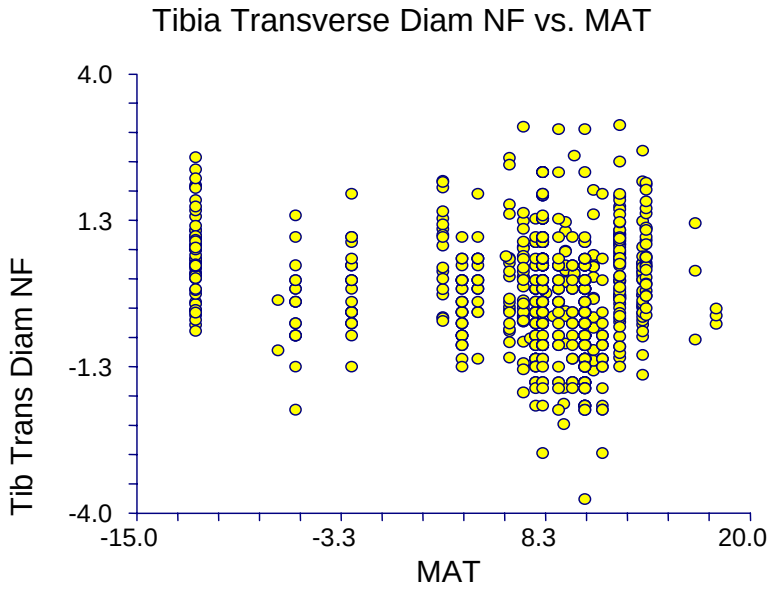


Figure A.26. Tibia transverse diameter at the nutrient foramen vs. mean annual temperature.

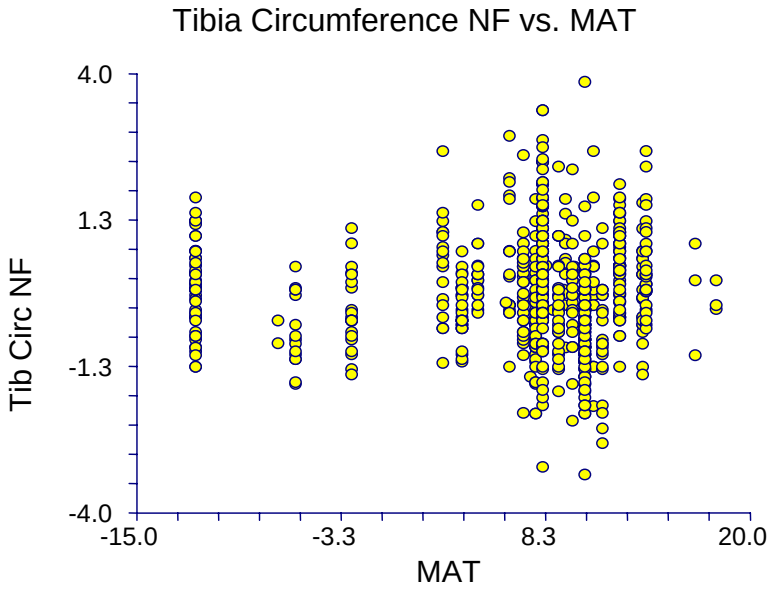


Figure A.27. Tibia circumference at the nutrient foramen vs. mean annual temperature.

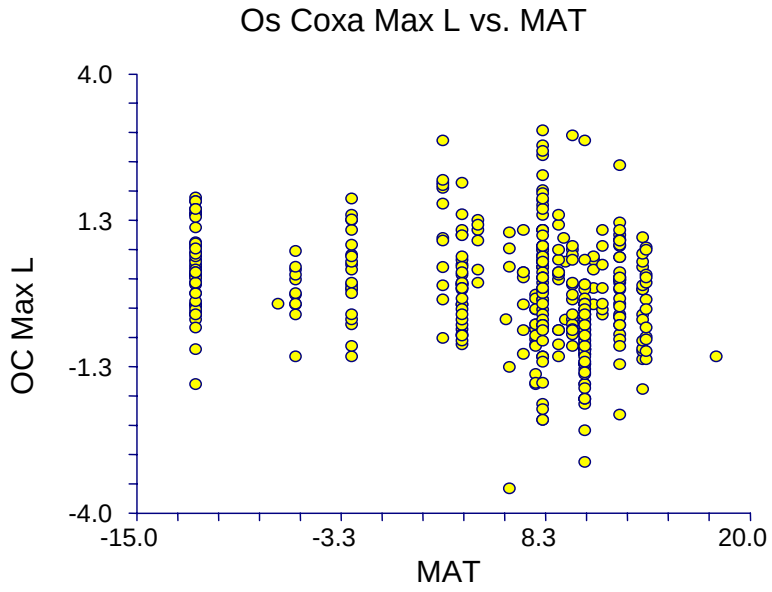


Figure A.28. Os coxa maximum length vs. mean annual temperature.

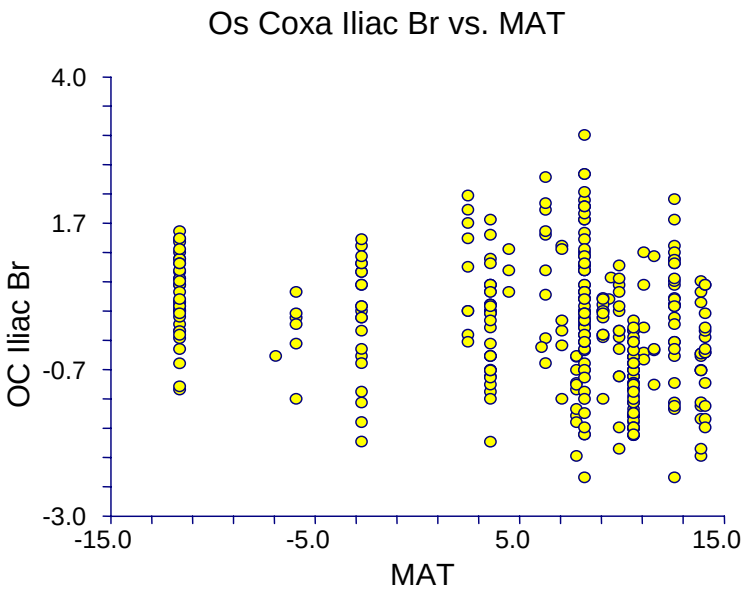


Figure A.29. Os coxa iliac breadth vs. mean annual temperature.

Vita

Kathryn A. King was born August 10, 1978 in Charleston, West Virginia. She graduated from Capital High School in Charleston in 1996. She went on to the University of Kentucky, where she studied Chemistry and Spanish before deciding to major in Anthropology. She received her B.A. from the University of Kentucky in 2000. She received her M.A. in Anthropology at the University of Tennessee in December 2002, where she remained to pursue her Ph.D. While at the University of Tennessee she has served as a graduate assistant to the Forensic Anthropology Center and as a graduate teaching assistant and later graduate teaching associate in the Department of Anthropology. Katie currently resides in Knoxville, Tennessee.